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RESERVOIR ANALYSIS MODEL FOR BATTLEFIELD OPERATIONS

by

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This report documents the development of a new analysis procedure which can be utilized by Army field commands to incorporate reservoir drawdown planning considerations into battlefield assessments. An overview illustrating the impacts of hydrology on the battlefield is presented initially to highlight the importance of induced flooding operations on military strategy and tactics. The Reservoir Analysis Model for Battlefield Operations (RAMBO) concept is then examined in detail utilizing a series of summary tables and stepwise guides; these procedures incorporate military requirements, hydrologic modeling and statistical analysis techniques into a comprehensive planning process. A case study approach is then employed to demonstrate the utility of the RAMBO analysis procedures for conducting a reservoir drawdown study in a military theater of operation. Six drawdown strategies are evaluated for the Han River Basin in Korea. Artificial

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SUMMARY

This report documents the development of a new analysis procedure which can be utilized by Army field commands to incorporate reservoir drawdown planning considerations into battlefield assessments. An overview illustrating the impacts of hydrology on the battlefield is presented initially to highlight the importance of induced flooding operations on military strategy and tactics. The Reservoir Analysis Model for Battlefield Operations (RAMBO) concept is then examined in detail utilizing a series of summary tables and stepwise guides; these procedures incorporate military requirements, hydrologic modeling, and statistical analysis techniques into a comprehensive planning process. A case study approach is then employed to demonstrate the utility of the RAMBO analysis procedures for conducting a reservoir drawdown study in a military theater of operation. Six drawdown strategies are evaluated for the Han River Basin in Korea. Artificial intelligence techniques are then examined highlighting the use of expert systems for Military Hydrology applications, specifically the reservoir drawdown problem. Finally, a next generation notional concept for the RAMBO concept is presented incorporating a wide range of military requirements (dam-break analysis, trafficability considerations, rainfall-runoff predictions, and tactical weather radar systems) into an intelligent decision support package based on AI technology.

PREFACE

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The Commander and Director of WES was COL Dwayne G. Lee, EN. The Technical Director was Dr. Robert W. Whalin.

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CHAPTER I

INTRODUCTION

BACKGROUND

Throughout the history of warfare, hydrology has played an increasingly important role in the planning and execution of military operations. The technological improvements of military weapons systems coupled with the growth of industrialization throughout the world's military theaters of operation have changed both the operational and tactical levels of war. Military commanders today are confronted with problems of unprecedented complexity that require the application of both classical and modern warfare theories to secure and retain the initiative. Historical accounts clearly indicate that in almost every major military campaign hydrology has proven to be a dominant factor. Flooded river crossing sites, flood-severed logistical supply lines, insufficient water supply, and reduced trafficability are all hydrologic problems which disrupt military timetables and affect both the planning and execution of tactical operations (Stinson, 1981).

The modern AirLand Battle doctrine dictates that hydrologic support to the Army must be compatible with current operational concepts and complement the dynamic elements of the modern battlefield. It is clearly evident, though, that most Army field manuals and operating procedures describe hydrologic warfare doctrine in terms of antiquated systems and outdated techniques. Significant improvements in hydrologic modeling have occurred during the past fifteen years with

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The format and style of this thesis follow the pattern of the Water Resources Bulletin.

the advent of desk-top computers, expert systems, and sophisticated software packages; unfortunately though, many of these improvements have not been integrated into the current AirLand Battle strategy and planning procedures.

In January 1983, the U.S. Army Corps of Engineers (USACE) was tasked to implement a Research, Development and Evaluation program specifically tailored to the AirLand Battlefield. The objectives of this research effort were to develop improved technologies and operational capabilities to enable field Armies to perform rapid battlefield assessments during military operations. The Military Hydrology (MILHY) research program, approved in 1977 by the Office of the Chief of Engineers, became an important sublevel in the USACE AirLand Battlefield Environment Thrust (ALBE) project. The principal objective of the MILHY program was to develop and improve hydrologic capabilities of the Armed Forces with emphasis on applications in tactical environments. The MILHY program was divided into four research thrust areas for control and coordination: (a) weather-hydrology interactions, (b) state of the ground, (c) streamflow, and (d) water supply. Although all four areas have significant impact on military planning and operations, the third area, streamflow, will be the focus of this thesis.

The streamflow research area is oriented towards the development of computerized procedures for rapidly forecasting the downstream impacts of floods. Recent efforts have been directed principally toward induced flooding under either dam breach or controlled release scenarios. Although this battlefield analysis capability is extremely important, another area of interest which has received little or no attention is the study and evaluation of military reservoir operations. Modern strategy and tactics must take into account the physical and hydraulic characteristics of reservoir systems within military theaters of operation because of their significant potential for hydraulic warfare applications. Reservoir systems provide the military commander with in-place weapons that can be used in numerous ways to influence the course of the battle and project superior combat power at the decisive time and place. Several realistic examples include (a) influencing the location and operation of military installations in areas subject to inundation, (b) disrupting river crossing operations, and (c) maintaining sufficient streamflows to create an impassable linear water obstacle. Military reservoir operations have implications for the civilian population as well. Water supply, irrigation, hydroelectric power generation, and navigation can be severely affected by the regulation of the reservoir system strictly for military purposes; these factors, in turn, could have serious repercussions on food supply, industrial operations, commerce, and public health.

It is evident that the military planner must have the technological tools and capabilities to analyze the complexities associated with operating reservoir systems in theaters of war. Without these tools the planner stands little chance of maximizing the utilization of his water resources in conjunction with battlefield operations.

PURPOSE

The primary purpose of this thesis is to present an integrated set of procedures which can be used to analyze and evaluate reservoir drawdown contingency operations within military theaters of operation. The analytical procedures collectively entitled "Reservoir Analysis Model for Battlefield Operations" (RAMBO) combine computer model simulations, spreadsheet calculations, and statistical analyses into a comprehensive package. The RAMBO concept will provide the military decision maker with an enhanced capability which can be used to evaluate the impacts of differing reservoir drawdown strategies on existing operational and contingency plans.

SCOPE

This thesis represents the fourth report contributing to research in the streamflow thrust area. The report will be presented in six chapters. Chapter 1 will examine the reservoir drawdown problem from a military perspective and define the objective of this research project. Chapter 2 will highlight the influence of hydrology in the planning and conduct of military operations and present an historical perspective demonstrating the tactical use of induced flooding operations on the battlefield. Chapter 3 will describe the analytical analysis procedures and numerical modeling techniques that form the basis for the RAMBO concept. Chapter 4 will highlight an applied case study utilizing the RAMBO concept to evaluate reservoir drawdown contingency planning for a South Korean river basin. Chapter 5 will describe the integration of the RAMBO concept into an expert system framework and focus on a prototype software package developed for the U.S. Forces Korea engineer staff. Finally, Chapter 6 will include major conclusions, and recommendations for further research.

PROBLEM

The use of hydraulic warfare to influence the outcome of battlefield operations is well documented. The fact that this destructive capability exists and can be used by either friendly or enemy forces to seize or retain the initiative on the battlefield definitely warrants consideration in the preparation of military theater contingency plans. Studies conducted by the USACE Military Hydrology R&D Branch (1957) resulted in the publication of twelve military hydrology bulletins and three technical bulletins (Table 1).

Table 1. Military hydrology and technical bulletins prepared by the USACE Military Hydrology R&D Branch

Military Hydrology Bulletins (MHB).

1. MHB 1: Applications of Hydrology in Military Planning and Operations
2. MHB 2: River Characteristics and Flow Analyses for Military Purposes
3. MHB 3: Stream-Gaging
4. MHB 4: Transmission of Hydrologic Data for Military Purposes
5. MHB 5: Card-Indexing and Filing of Information Pertinent to Military Hydrology
6. MHB 6: Directory to European Sources of Information on Military Hydrology
7. MHB 7: Glossary of Terms Pertinent to Military Hydrology
8. MHB 8: Selected References on Military Hydrology
9. MHB 9: Flow Through a Breached Dam
10. MHB 10: Artifical Flood Waves
11. MHB 11: Regulation of Stream Flow for Military Hydrology
12. MHB 12: Handbook of Hydraulics

Department of the Army Technical Bulletins (TB).

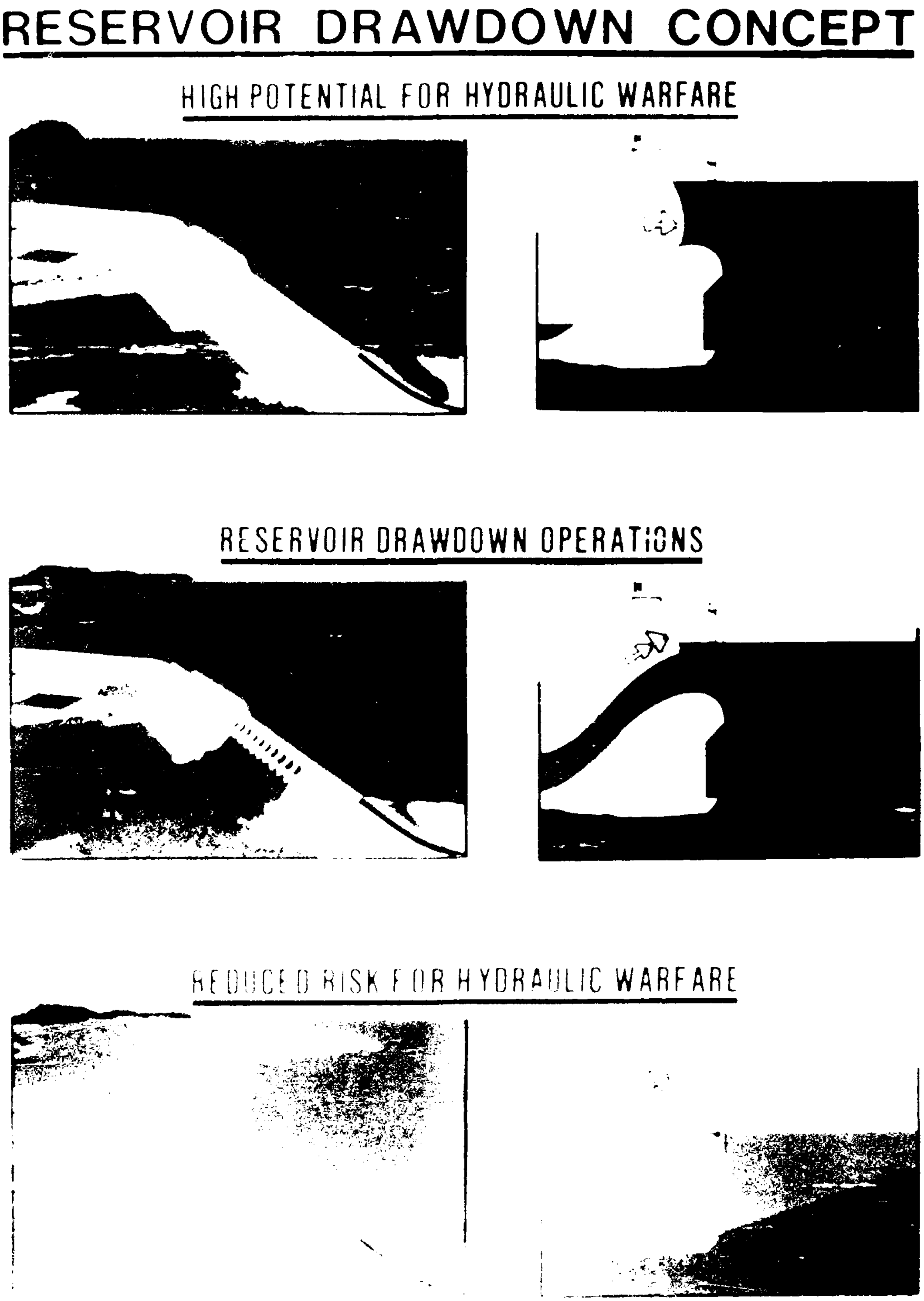
13. TB 5-550-1: Flood Prediction Services
14. TB 5-550-2: Compilation of Intelligence on Military Hydrology
15. TB 5-550-3: Flood Prediction Techniques

A review of these fifteen publications indicated that the military was concerned with the destructive implications of hydraulic warfare along with other pertinent aspects of hydrology impacting on military operations and felt it was necessary to devise data collection techniques and hand computational analysis procedures to aid in planning and evaluating the potential impacts of these operations on the battlefield. Following the publication of these bulletins in 1957 and 1958, very little research was done by the USACE until the implementation of the Military Hydrology program in 1977.

The main thrust of military hydrology research over the past thirty years has been focused on analyzing the implications of hydraulic warfare operations from the standpoint of effects inflicted on the battlefield. Although this is an important consideration in military planning, it is equally essential to analyze the reciprocal course of action; i.e., how can the impacts of hydraulic warfare be reduced or eliminated without degrading U.S. military operations?

The most essential requirement necessary for hydraulic warfare is an adequate amount of water. Reservoirs, impounding large volumes, represent the most significant sources of water that could be used to conduct hydraulic warfare operations within existing military theaters. Usable storage refers to the volume of water located above the spillway that could be released without total destruction of the dam or barrier. A logical step that could be taken by military commanders to reduce the potential impacts of enemy-induced flooding would be to lower the reservoir water surface to the spillway level (See Figure 1). After the execution of reservoir drawdown contingency operations (usable water storage removed), the potential hydraulic warfare impacts would be significantly reduced, and the only course of action left open to the enemy would be to destroy the main structure of the dam using a large amount of explosives or a nuclear device.

The strategic and tactical issues surrounding the reservoir



[illegible] Illustration depicting the reservoir drawdown problem. The top view indicates a high potential for induced flooding: the middle view illustrates the execution of reservoir drawdown operations; the bottom view indicates a reduced risk of enemy-induced flooding.

drawdown problem are complex. The first key issue concerns the implications of hydraulic warfare operations. If the military commander were to draw down strategic reservoirs within his area of operations, he effectively could reduce or eliminate the possibility of enemy-induced flooding. Conversely, these actions degrade the commander's own hydraulic warfare capability, which could have been used defensively to disrupt or delay enemy offensive operations. A second issue concerns the actual drawdown time and the resulting loss of usable water. If an enemy attack is imminent, what is the expected safe drawdown time and what impact does the loss of usable water have on municipal and industrial water supply and hydroelectric power generation? A third issue concerns the effects of reservoir drawdown operations on downstream crossing sites. If reservoir drawdown operations are initiated, can downstream tactical crossing sites remain in operation and under what conditions would the sites have to be closed? These represent some of the major issues confronting the military commander which would have to be considered when evaluating the feasibility of alternative reservoir drawdown contingency plans.

Currently, the military lacks the technological tools and analytical procedures to realistically evaluate the consequences of proposed reservoir drawdown plans. This thesis will address the reservoir drawdown problem and propose an integrated set of procedures (RAMBO) which can be used by military planners to

a. Model river basins in contingency areas using state-of-the-art computer simulation techniques.

b. Evaluate reservoir drawdown times.

c. Evaluate maximum river crossing site flow rates.

d. Assess the military advantages and disadvantages of each drawdown plan with regard to tactical and contingency operational plans (OPLANS).

This overall capability will, for the first time, enable military planners to realistically assess the impacts, advantages, and disadvantages of each reservoir drawdown contingency plan. Staff estimates can now provide the commander with previously unavailable information that can help him formulate an improved estimate of the situation. Contingency and battlefield OPLANS can now include the impacts of reservoir drawdown operations, which previously were considered in broad, indefinable terms or not at all.

The next chapter will discuss the role hydrology plays in military operations. It is essential to understand the tactical implications of adverse hydrologic conditions on the battlefield in order to fully comprehend the complexities surrounding the reservoir drawdown problem.

CHAPTER II

THE IMPACTS OF HYDROLOGY ON THE BATTLEFIELD

THE ROLE OF HYDROLOGY IN MILITARY OPERATIONS

The complexion of the modern battlefield has drastically changed due to the technological advances of recent years. Highly mobile weapons systems, ground/satellite surveillance techniques and advanced communication devices have added a new dimension to warfare and become the trademarks of today's modern military forces. Despite these vast changes in technology, the physical factors of weather and terrain are as significant today as during the campaigns of Alexander the Great, Frederick the Great, and Napoleon.

Following the expansion of the French Empire in 1806, Napoleon described the influence of weather on battlefield operations as the "Fifth Element" of warfare (Brinns, 1972a). Britt (1973) describes the Napoleonic campaigns of Ulm and Austerlitz, which occurred on the battlefields of Central Europe over one hundred and eighty years ago. During these campaigns the effects of weather and hydrology had a pronounced impact on Napoleon's advances against the Austrian and Prussian forces. Figure 2 depicts the nine-hundred-mile advance of Napoleon's forces from the French coast to Vienna and the long lines of communication established to support the advancing army. Heavy rains and sleet during October and November of 1805 had a severe impact on both personnel and equipment by turning both attack and logistical resupply routes (lines of communication) into roads of mud. Despite the weather, supply shortages, and other battlefield factors, Napoleon was victorious over Alexander's army and subsequently imposed peace on Austria and Prussia. Although Napoleon's generalship and flexible strategy enabled the Grand Armee to overcome the detrimental effects of poor weather during their battlefield operations, today's military leaders may not enjoy the same degree of versatility due to the changes in modern strategy and tactics necessitated by technological advances in military equipment and weapons systems.

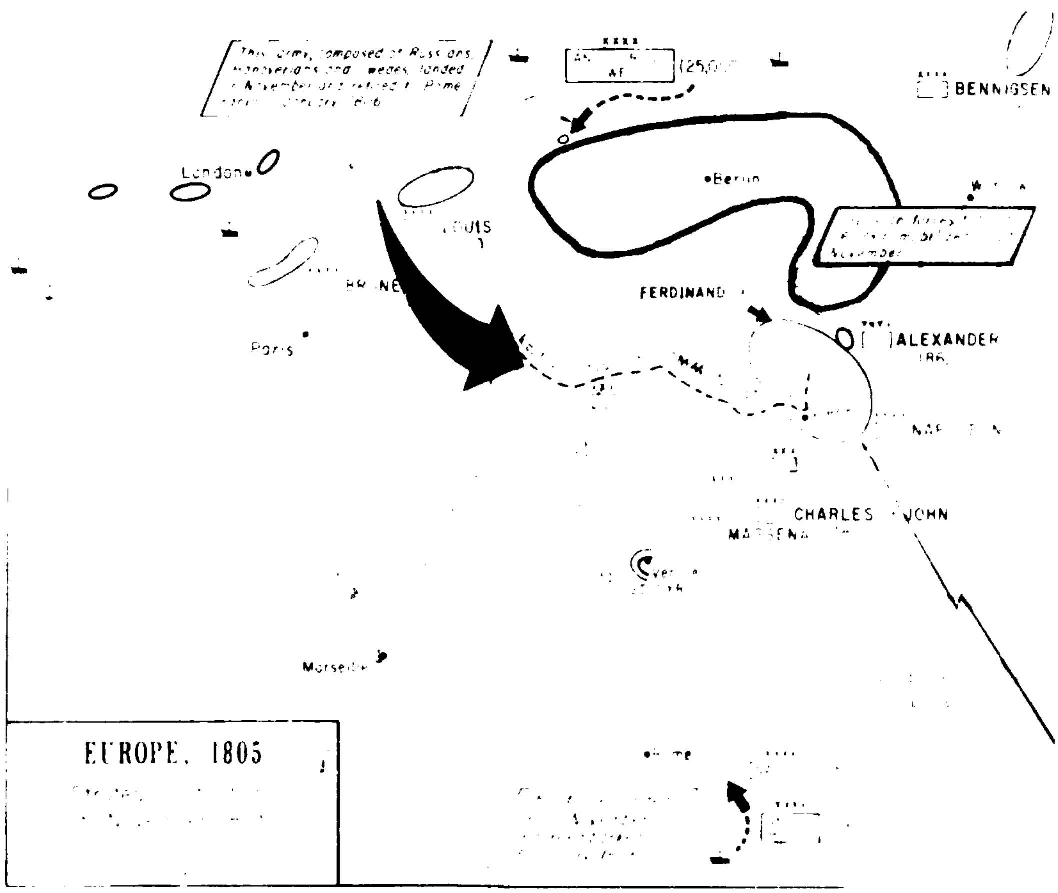


Figure 2. The strategic situation in Europe following the Ulm Campaign in 1805.

(Espetio and Elting, 1964)

During World War II the Germans were not as fortunate as Napoleon. Brinns (1972a) indicated that their offensive against the Russians in 1941 was severely influenced by hydrologic conditions during advances conducted in October and November. Heavy rains turned the roads into quagmires of mud and off-road maneuverability was generally impossible. Rivers throughout the area of operations became swollen and flooded, creating problems for the motorized resupply columns. The German offensive fell short of its final tactical objectives; rain, snow, and mud proved to be greater enemies than the defending Russian forces. It is not clear whether the Germans failed to fully anticipate the role weather would play in their offensive, but it is evident that the rain and mud crippled their early winter advances and contributed towards their eventual loss of the war.

These two historical examples illustrate an important concept; the combat leader who understands, anticipates and plans for the impacts of hydrology on personnel, equipment, terrain, and military operations will have a tactical advantage over the leader who does not. Recognizing hydrology and its influence on battlefield operations is a distinction that separates veteran combat leaders from "Great Captains" of military history like Napoleon, Jomini, and MacArthur. These men understood and anticipated the impacts of weather on military operations and were prepared to react and seize the initiative under adverse hydrologic conditions. The weather, though, is an unpredictable element of warfare; how can a military leader use hydrology to influence the course of the battle at his own time and choosing?

THE CONCEPT OF INDUCED FLOODING

Induced flooding is not a new concept in warfare. Its effective uses in World War II, the Korean Conflict, and the Iran-Iraq War are well documented. Consider the historical account given by Flocke (1988) of a battle that occurred over one hundred and fifty years ago on the plains of Texas.

The battle of San Jacinto was fought on April 21, 1836; it was the turning point in the Texas fight for independence from Mexico. On that spring day, General Sam Houston decisively defeated General Antonio Lopez de Santa Anna, a self-styled "Napoleon of the West." General Houston used the weather to his advantage, trading space for time, defeating an army one and a half times the size of his own. While retreating from the Mexican Army, General Houston's forces burned bridges and ferries, delaying the advance of General Santa Anna's men during high flood stages along both the Brazos and Colorado Rivers. This delay enabled General Houston to reorganize his force, train his men and prepare for a counterattack against the unsuspecting Mexican Army. After the rivers subsided, General Houston's forces conducted a hasty river crossing operation on the Buffalo Bayou and soundly defeated the Mexican Army during a surprise attack. General Houston used the flooded river conditions to his advantage and ultimately defeated a superior larger force.

The key element in this example was the delay of the Mexican offensive due to the flooded river conditions. Suppose a military commander could create a linear water obstacle at the time of his choosing by flooding a river or pumping water into a man-made barrier.

This form of man-made induced obstacle would represent a significant force multiplier having military applications during the conduct of both offensive and defensive operations.

What is the concept of induced flooding and how can it be initiated during a combat operation? Figure 3 illustrates the breaching sequence at a dam using an aerial-delivered munition. The resultant floodwave could create a linear obstacle in the downstream floodplain region (Figure 4) effectively delaying an enemy advance or severing his rear area lines of communication. This breaching method was used effectively by the British during World War II.

Induced flooding can also be created under controlled conditions through the use of gated reservoir releases. Pulsating flood waves could be propagated throughout downstream river reaches by opening and closing the gated spillways. This type of induced flooding could be timed to occur at a decisive point in the battle, maximizing its military value. This method was used effectively by the North Korean's during the Korean Conflict.

A third method of creating induced flooding on the battlefield would be to pump water into prespecified tactical zones creating an impassable water barrier. This method has been used effectively by both military forces during the Iran-Iraq War.

INDUCED FLOODING OPERATIONS FROM AN HISTORICAL PERSPECTIVE

"Dam Busters" was a nickname given to the crack R.A.F. tactical bomber squadron known as X Squadron; they executed a famous bombing raid against three large German dams during World War II. Dziuban (1947) recounts that on the evening of May 16, 1943, eighteen bombers

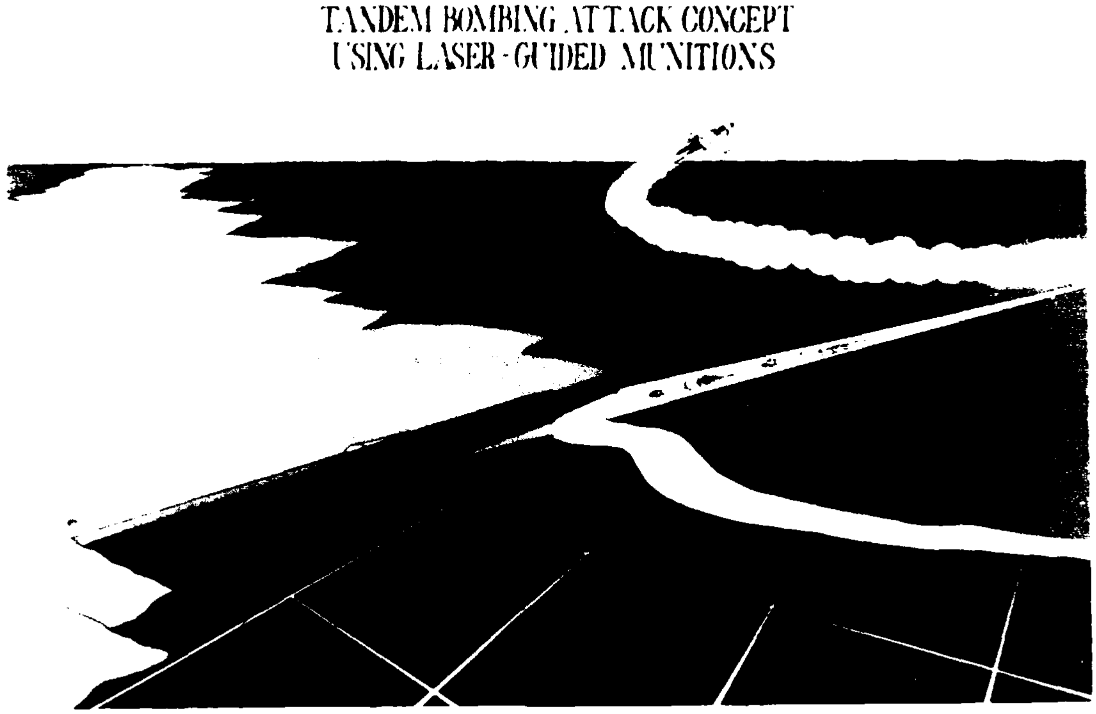


Figure 3. Illustration of an aerial delivered munition breaching an earthen dam on the battlefield.

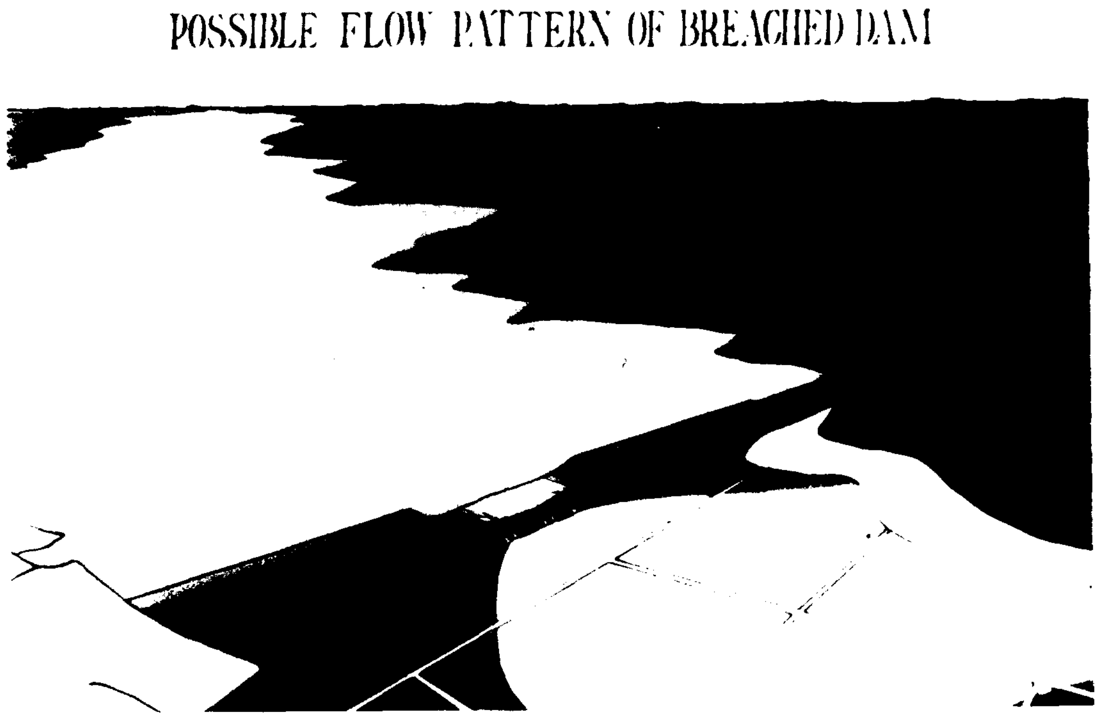


Figure 4. Illustration depicting the downstream floodwave impacts created under a dam breach scenario.

took off from England to attack three strategic targets in Germany. The crews had trained with a completely new bombing device, called the "Wallis or Skip Bomb," for the previous month. Their targets were the Mohne, Sorpe, and Eder Dams located in the heart of the Ruhr industrial valley. If the dams could be breached using this new device, the resultant impacts could be more severe than any other single event during the European war; these dams held back over seventy-six percent of the total available water in the Ruhr valley. The bombing raid was executed with perfection against both the Mohne (Figure 5) and Eder Dams; the Sorpe Dam could not be breached because of its thick structure and extensive foundation design. Although only two of the three primary targets were breached, serious flood damage occurred throughout the downstream region (Figure 6). Thousands of acres of agricultural land were despoiled, ruining over seventy percent of the yearly harvest. Industrial stoppages occurred in the Ruhr valley resulting from the loss of electrical power, the shortage of water, and washed out highways and railroads. Although the bombing raid did not cripple the overall German war effort as originally anticipated, the short term regional effects were significant. This example of induced flooding illustrates a strategic application under a dam breach scenario to interdict rear area operations.

The second historical example of induced flooding, recounted by Fowler (1952), occurred during the Korean Conflict in the spring of 1951. North Korean forces held the terrain north of the 38th Parallel, while United Nations forces occupied defensive positions south of the parallel along both sides of the North Han River. Hwachon Dam,

Figure 5. Aerial photographs taken by reconnaissance planes before (left) and after (right) the bombing raid on the Mohne Dam. The final breach approximated a trapezoid measuring 100 meters across and 33 meters deep.

(Jablonski, 1971)

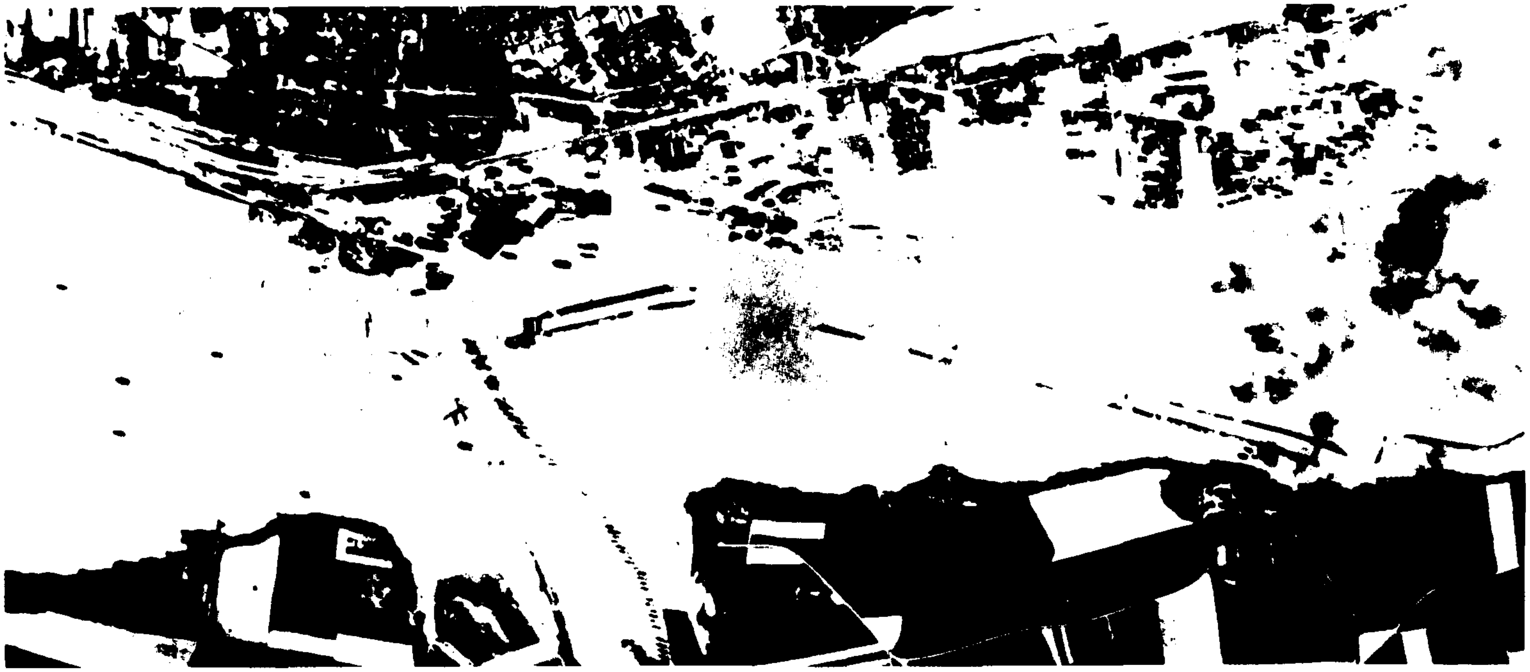


Figure 6. The effects of the induced floodwave created by a breach in the Mohne Dam inundated a large portion of the downstream Ruhr industrial valley.

(Brinns, 1972b)

controlled by North Korean forces, was located approximately 10 miles north of the parallel; it was one of the largest dams in Korea and contained approximately one billion cubic meters of storage. The concrete gravity dam had eighteen spillway gates thirty-two feet in height along the top of the structure (Figure 7). The United Nations

Figure 7. Aerial view of Hwachon Dam, April 1951, looking south. (Fowler, 1952)

forces had two tactical float bridges in place south of the dam to maintain supply and lateral movement routes across the river (Figure 8). At 7:15 A.M. on April 9 the North Korean forces opened ten of the flood gates at Hwachon Dam; the resultant flood wave created by this large release of water severed both tactical float bridges deployed downstream of the dam. Both bridge sites remained closed until April 11; the North Koreans had effectively induced a flood throughout the downstream reaches of the river that created a forty-eight hour loss of lateral movement for the United Nations forces. In

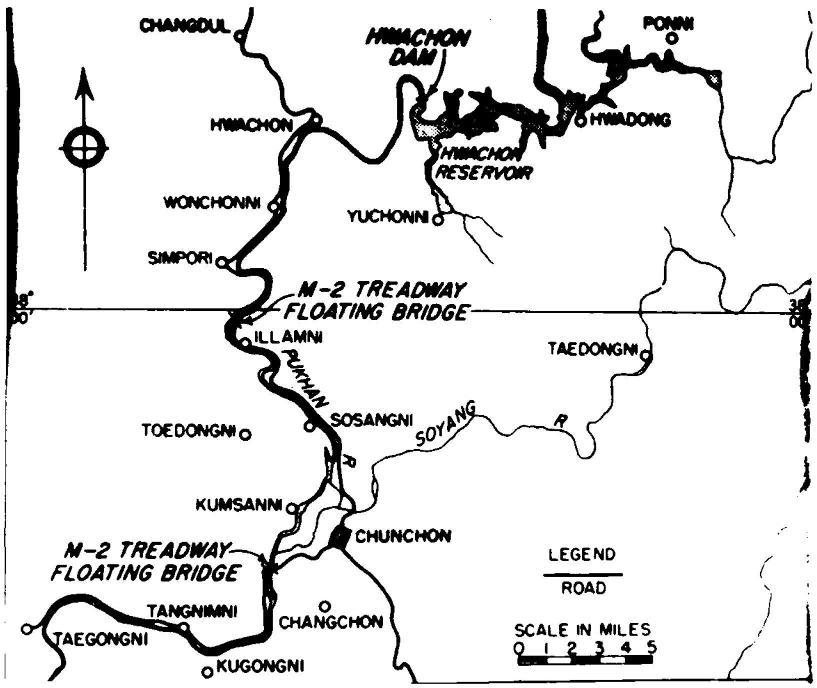


Figure 8. Map depicting the location of Hwachon Dam and the M-2 float bridge sites

(Fowler, 1952)

late May, U.S. naval torpedo bombers attacked the dam (Figure 9) and effectively destroyed three of the spillway gates; at this point, the dam lost its tactical significance because induced flooding could no longer be employed. This example of induced flooding illustrates its tactical military use under a controlled reservoir release scenario to interdict operations in the main battle area.

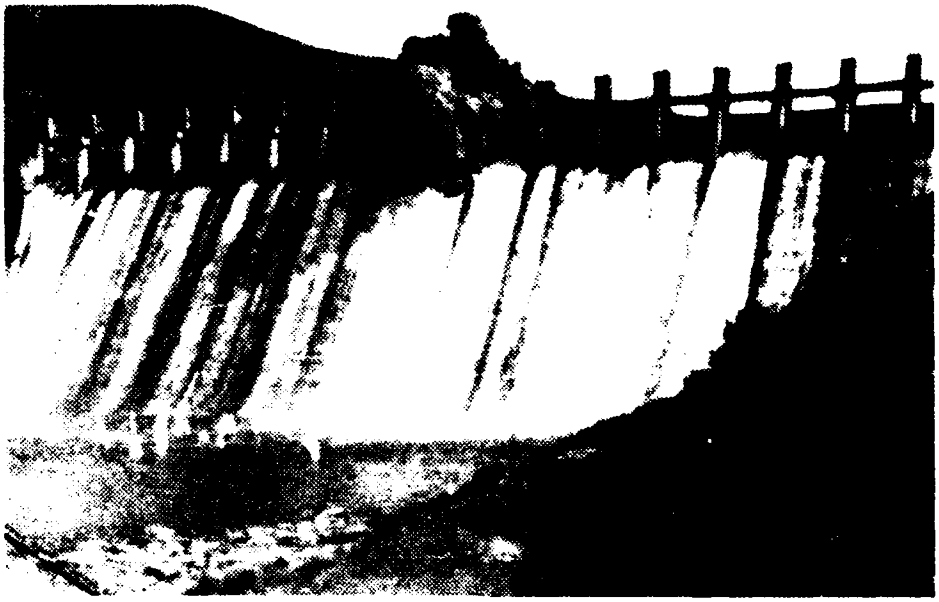


Figure 9. Destruction of spillway gate nine by torpedo bombing (Fowler, 1952)

The final historical example of induced flooding operations occurred during the Iran-Iraq War in 1987. At the southern end of the border between the two countries, the terrain offered the most favorable conditions for conducting military operations. Abercrombie (1988) indicated, utilizing SPOT (Satellite Pour l'Observation de la Terre) satellite imagery (Figure 10), that Iraq created a barrier along the border by pumping water into a fifteen hundred square mile area. This water barrier was three to nine feet deep and denied the Iranian forces use of the central attack sector. In effect, Iraq had channelized any potential Iranian offensive into a narrow zone north or south of the obstacle. Iraqi forces could then target weapon systems in these two attack corridors gaining a significant tactical advantage. Iran responded with its own water obstacle by flooding an area surrounding the Karun River. Both forces have realized the tactical importance of induced flooding and employed it effectively under a defensive posture.

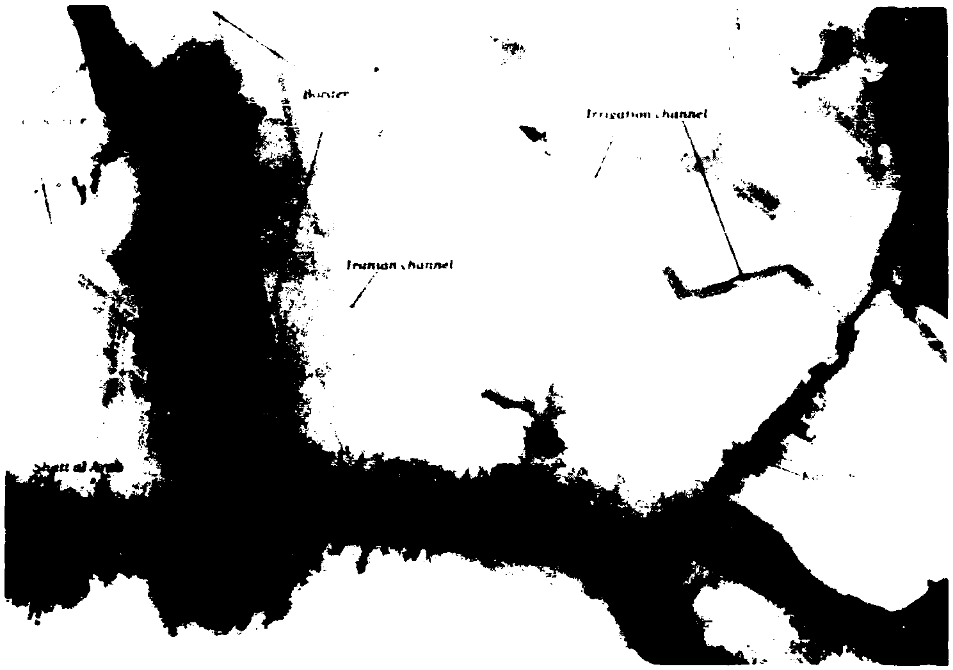


Figure 10. SPOT satellite image depicting the tactical use of water to create linear barrier obstacles near the Iraqi-Iranian border.

(Abercrombie, 1988)

All three examples highlight the strategic or tactical effectiveness of induced flooding during the conduct of military operations. The immediate consideration is how can a military commander defend against hydraulic warfare, especially in his own rear area? Consider the first situation. If the Germans had been able to draw down the water level in the Mohne and Eder Reservoirs, would the regional flooding effects have been so pronounced throughout the Ruhr industrial valley? In the Korean situation, if the United Nations forces had occupied the area north of the Hwachon Dam (such as occurred four days later on April 18, 1951) and had North Korean forces infiltrated the dam site using a Special Forces operation, could they still have severed the tactical float bridges across the river if reservoir drawdown operations had been initiated by the United Nations forces after initially securing the dam? In both these scenarios, how long would it have taken to draw down the reservoirs without hindering tactical operations downstream of the dams? Without some form of tactical decision aid, the military commander would be hard pressed to evaluate these situations properly and select the appropriate course of action.

U.S. military forces are presently confronted with these same concerns when developing contingency plans in likely combat theaters. No form of computerized analysis technique exists that enables military planners to incorporate reservoir drawdown planning considerations into their contingency OPLANS. The next chapter will describe a solution to this problem utilizing an integrated analysis technique entitled the RAMBO concept.

CHAPTER III

RAMBO INTEGRATED ANALYSIS PROCEDURES

MODEL COMPONENTS

The RAMBO concept was specifically developed to evaluate reservoir drawdown contingency plans under a military threat scenario. The concept involves the incorporation of three existing computer software routines - HEC-5 Simulation of Flood Control and Conservation Systems Model (The Hydrologic Engineering Center, 1982), Symphony Program (The Lotus Development Corp., 1985) and SAS Statistical Analysis System (SAS Institute Inc., 1985) - into a five-phase analysis procedure Figure 11). This innovative concept blends military battle staff assessments, hydrologic modeling, and statistical analysis procedures, offering the engineer planner a tactical decision tool capable of incorporating the dynamic nature of reservoir operations into battlefield contingency OPLANS.

Phase I

As shown in Table 2, specific actions that must be completed by the military battle staff to properly establish the scope of the reservoir drawdown problem under consideration are defined in the first phase of the RAMBO procedures. The Operations and Intelligence Sections of the commanders staff will complete these actions utilizing tactical and contingency OPLANS, intelligence and situation reports, engineer river reconnaissance, and floodwave impact assessments. If their evaluation indicates the possibility of an induced flooding threat within the theater of operation, reservoir drawdown contingency

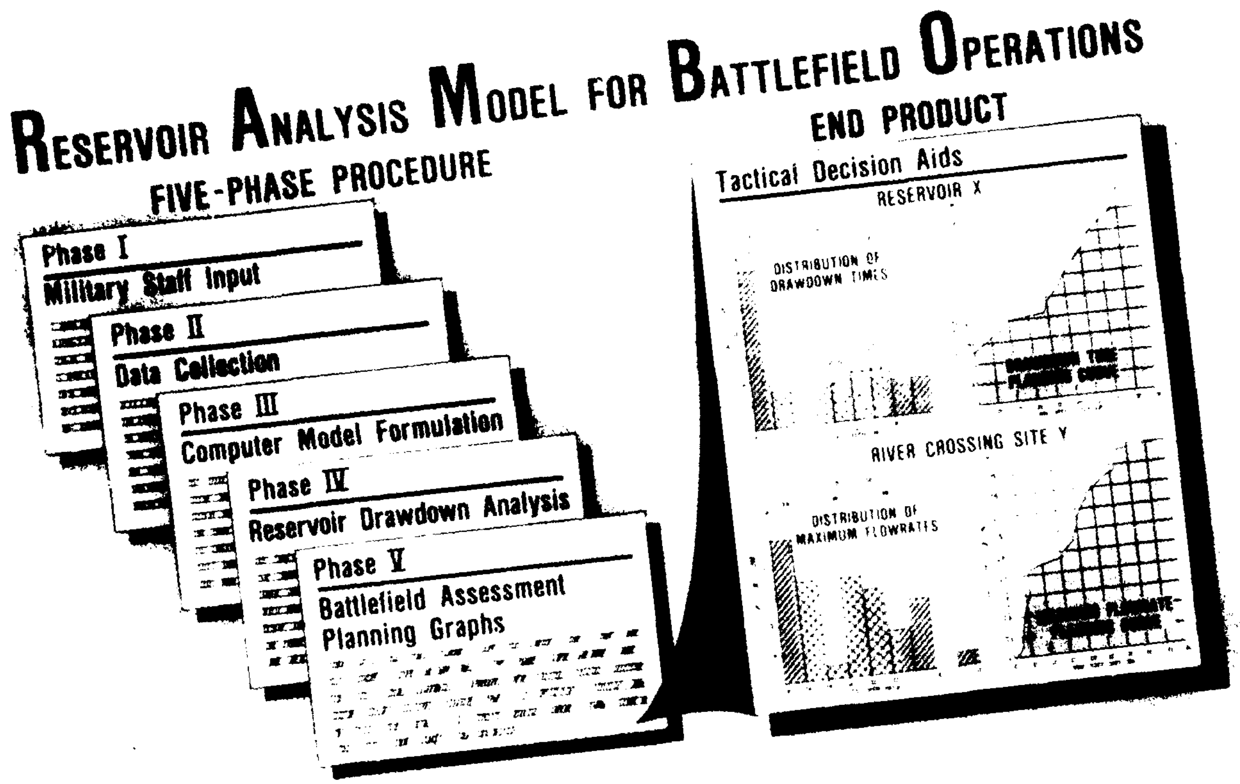


Figure 11. Flow chart depicting the five-phase RAMBO analysis concept

analyses will be warranted utilizing the RAMBO procedures. Appropriate river crossing sites and specific drawdown contingency scenarios will be determined based on the commander's tactical requirements. If the use of induced flooding appears unlikely within this area of operation, a reservoir drawdown study will not be justified.

Table 2. Phase I requirements: Military staff input

1. Specify the military Area of Operation (AO) under consideration.

   a. Define the boundaries for the AO
   b. Provide a general description of the topography
   c. Provide a general description of the drainage system
   d. Specify the reservoir(s) to be evaluated during the analysis

2. Quantify enemy capabilities for capturing or destroying reservoirs within the AO using the following categories.

   a. Ground attack operations
   b. Special Forces operations
   c. Air attack and indirect fire operations

3. Conduct an evaluation of the induced flooding potential for the AO (dam-breach/controlled release modeling study).

4. Identify the reservoir drawdown contingency scenarios to be evaluated (include constraint guidelines).

   a. Specify scenarios to be evaluated
   b. Identify the water storage policy that should be applied to downstream reservoirs during drawdown modeling
   c. Identify the acceptable channel capacities during reservoir drawdown operations (slow and fast drawdown).

5. Identify the river crossing site(s) to be included in the drawdown model study.

Phase II

Outlined in Table 3 is the second phase of the RAMBO procedures, i.e., the essential data requirements necessary to conduct a reservoir drawdown planning study. Data collection checklists, developed to aid the engineer analyst, synthesize the computer model input requirements into five basic categories: (a) reservoirs, (b) control points, (c) hydropower facilities, (d) time series inflows, and (e) water resource utilization maps. These checklists provide a valuable tool for identifying all necessary data requirements to build an HEC-5 model of the river basin.

Table 3. Phase II requirements: Data collection

1. Reservoir checklist requirements

    a. General dam and reservoir specifications
    b. Spillway data and rating curve
    c. Outlet works data and rating curve
    d. Power penstock rating curve
    e. Area-elevation curve
    f. Storage capacity-elevation curve
    g. Tailwater elevation-discharge curve
    h. Target pool operating levels
    i. Monthly net evaporation rates

2. Control point checklist requirements

    a. Location within river system
    b. Drainage area contributing to flow (area ratio factor)
    c. Diversion and return flow forecasts
    d. Maximum, minimum required, and minimum desired flows

3. Hydropower checklist requirements

    a. Powerplant operating characteristics
    b. Monthly at-site power requirements
    c. Powerplant peaking capability curve

4. Time series inflow checklist requirements

    a. Control point gaging location associated with measured inflow
    b. Category of flow (monthly, yearly, etc.)
    c. Time series flow records for the historical period

5. Map and basin checklist requirements

    a. Detailed map of the study area
    b. Key water resource land use areas
    c. River basin net evaporation rates

The accuracy of the input data will influence the model's ability to reproduce the flow patterns and operating characteristics of the river system; this in turn will affect the reliability of the drawdown results.

Phase III

As shown in Table 4, a stepwise guide for constructing a reservoir system input model constitutes the third phase of the RAMBO procedures; a reservoir system input model is essential for an application of the HEC-5 program. This mathematical simulation program, developed by the Hydrologic Engineering Center, is the central core of the RAMBO procedures. Although the program was originally developed as a civilian water resource planning tool (i.e., reservoir system operation studies, hydropower analysis, and flood control and conservation storage sizing evaluations), its structure and wide-ranging capabilities provide an excellent framework for integrating military reservoir drawdown requirements. Any complex reservoir system (parallel and tandem operation) can be simulated with the program. The critical computational asset provided by the program is its ability to simulate a flood control emergency situation (analogous to military reservoir drawdown operations) while minimizing flow damage throughout the downstream channel. Utilizing this program option and linking flow damage calculations to river crossing site constraints, any reservoir drawdown strategy can be simulated and subsequently evaluated. Although no complex physical situation can be exactly simulated by a numerical algorithm, the RAMBO procedures provide the military staff with a tactical decision tool commensurate with current technology.

Table 4. Phase III requirements: Computer model formulation

1. Develop a logic network for the river basin.

   a. Define the main and tributary river channels
   b. Specify reservoir and control point locations
   c. Identify diversion and return flow paths between control points

2. Identify the system hydrology requirements.

   a. Specify the streamflow data base for conducting the drawdown modeling
   b. Compute the river basin net evaporation coefficients

3. Define the characteristics and operating criteria for each reservoir.

   a. Specify basic reservoir characteristics

      1. Capacity-elevation curve
      2. Area-elevation curve
      3. Combined outlet capacity rating curve
      4. Monthly net evaporation coefficients

   b. Specify the operating criteria for each reservoir.

      1. Calculate storage capacity index levels (inactive, buffer, conservation, flood control, and top of dam)
      2. Define the reservoir rule curves

4. Define the hydropower plant characteristics and power requirements.

   a. Specify the basic powerplant operating characteristics

      1. Installed generating capacity
      2. Powerplant efficiency and overload ratio
      4. Penstock discharge capacity
      5. Fixed head loss
      6. Average tailwater elevation

   b. Specify the at-site power requirements for each reservoir based on system demand power loads

5. Specify the control point characteristics.

   a. Non-reservoir control points (river crossing site)

      1. Water demands
      2. Channel capacities
      3. Area ratio factors
      4. Minimum required/desired flow rates

Table 4. Continued

b. Reservoir control points

1. Maximum nondamaging flow rate
2. Minimum hydropower release flow rate

6. Specify the reservoir operation control point scheme.

Phase IV

The methodology for conducting a reservoir drawdown planning study, shown in Table 5, constitutes the fourth phase of the RAMBO procedures. This phase represents the most critical component of the procedural analysis. Military river crossing requirements and tactical strategies are translated into numerical quantities (maximum allowable flow rates and optimal reservoir water surface elevations), thereby establishing the basic controls for each reservoir drawdown strategy selected for evaluation. This stage of the RAMBO procedures requires the integrated use of all three computer programs (HEC-5, Symphony, and SAS) to complete a drawdown study.

The first step of the procedure is to conduct a model verification evaluation to insure that input data values are realistic and properly quantified. Following the verification process, base line conditions must be compiled for the river basin. The base line system can be established in two fashions, either developed with existing records or simulated with the HEC-5 program. If historical reservoir stage records exist, these should be organized in a summary table (base line system) and utilized to generate the starting storage volume matrix (described in step 3). If reservoir stage records do not exist, the HEC-5 program should be employed to generate this parameter based on

Table 5. Phase IV requirements: Reservoir drawdown analysis

1. Model verification guidelines

   a. Validate model-generated natural and incremental flows.
   b. Check maximum and minimum reservoir stage levels against defined limits.

2. Base line system formulation procedures

   a. Define the system operating strategy in terms of water policy goals (hydropower production and water supply demands).

   b. Conduct model runs and formulate the base line system through optimization of the water policy goals (item a).

3. Starting reservoir storage volume determination procedures

   a. Define the analysis period for the reservoir drawdown planning study (month, season, or year).

   b. Utilizing the base line system output and the Symphony program, generate the average reservoir storage levels for each period over the historical record.

4. Reservoir drawdown time and crossing site flow rate analysis procedures

   a. Specify the critical channel capacity for each control point based on the drawdown scenario guidelines (slow or fast drawdown rate).

   b. Modify all required top of conservation reservoir index levels to reflect the final required reservoir drawdown elevation (usually the spillway crest elevation).

   c. Choose the computational interval for the HEC-5 model simulation based on an estimate of the expected drawdown time.

   d. Modify the streamflow inputs to insure that a sufficient period of flow data is available to completely draw down the specified reservoir(s).

   e. Repeat this procedure for each period over the historical record to generate a statistical data base (drawdown time and maximum crossing site flow rate) for each drawdown strategy.

   f. After all periods have been simulated with HEC-5, record all drawdown times and maximum crossing site flow rates in a summary table.

Table 5. Continued

5. Statistical analysis of reservoir drawdown strategy results

   a. Statistically evaluate the drawdown results (drawdown time and maximum crossing site flow rate) utilizing the SAS program and the Proc Univariate analysis option. Statistical information provided with this option includes the mean, variance, and skewness.

   b. Generate a frequency table for both the drawdown time and maximum flow rate results utilizing the SAS program.

measured streamflow records. If simulated data are generated, linear programming optimization techniques are employed to maximize system hydropower output and minimize water supply shortages throughout the river basin based on the complete historical period of record. The system operating strategy that maximizes this objective function (i.e., maximizes hydropower production and minimizes water supply shortage periods) will be chosen as the base line system for all subsequent analyses.

Next, the starting reservoir storage volumes for all subsequent drawdown strategies are established; this parameter is the most crucial component of the drawdown analysis. The reservoir storage summary tables from the base line system (either measured or simulated), a defined drawdown analysis period, and the spread sheet option of the Symphony program, are then applied to calculate average reservoir storage volumes (i.e., starting reservoir water surface elevations) for each drawdown period over the historical record. This procedure is repeated for each reservoir in the river basin; the end product is a matrix containing starting reservoir storage volumes for each reservoir in the study area based on a selected analysis period.

The fourth step in the procedure incorporates key military tactical and strategic considerations into the drawdown analysis. Desired reservoir drawdown levels, maximum allowable outlet releases, and downstream river crossing site flow rates are specified based on the reservoir drawdown strategy chosen for evaluation. At this juncture all required input parameters have been numerically quantified and defined allowing drawdown model simulations to be initiated.

Utilizing the data base of starting reservoir storage volumes, measured streamflow rates at defined nodes in the simulated river system, and the HEC-5 program, model simulations are conducted for each analysis period contained in the historical record. Reservoir drawdown times and maximum river crossing site flow rates are recorded in a summary table for each specified location based on the drawdown strategy chosen.

As an example, if forty-one years of monthly historical streamflow records were used to define the base line system and a winter season analysis period (December, January, and February) was selected for the drawdown evaluation, forty computer model simulations would be required for each drawdown strategy to establish the statistical distribution of probable drawdown times and maximum river crossing site flow rates. If the drawdown strategy involved two reservoirs and three river crossing sites, the Symphony program would be used to define the average starting reservoir storage volumes for each reservoir over the forty winter seasons, and the HEC-5 program would be used to simulate the selected drawdown strategy. Forty drawdown times would be calculated for each reservoir, and forty maximum flow rates would be determined for each crossing site; these values would be recorded in a summary table and evaluated statistically.

The final step is to statistically evaluate the summarized drawdown results using the SAS program and Proc Univariate analysis option. The key parameters provided by this option include the mean, standard deviation, and skewness. These three statistical moments characterize the drawdown results in terms of central tendency (probability about a central value), variability, and degree of asymmetry for the distribution. These statistical values, along with the corresponding frequency tables, will be used during the fifth phase of the RAMBO procedures to quantify the drawdown results and generate the battlefield assessment planning graphs (the final analysis product).

Phase V

The fifth phase of the RAMBO procedures, depicted in Table 6, entails the development of the graphical end products (battlefield assessment planning graphs) which summarize the key military planning requirements associated with a particular reservoir drawdown strategy. These graphical decision aids consist of two analysis products, a frequency histogram and a cumulative frequency distribution; both are generated for the drawdown time and maximum flow rate results. The significance of these products is directly attributable to their value for making statistical inferences, i.e., incorporating the concept of probability into the military decision-making process.

As an example, using the frequency histogram of drawdown times (continuous variable) and the concept of probability relating to relative frequency, the military planner could assign a specific probability of occurrence for a particular range of drawdown times. This probability could be incorporated into contingency plans and used to determine the expected time frame in which key downstream locations would be vulnerable to enemy-induced flooding based on estimated enemy advance rates and projected strengths of friendly forces. The same form of information could be acquired from the cumulative frequency distribution for drawdown times since it represents a continuous projection of the data incorporated in the histogram; both graphical products are useful because they display synonymous information in two

Table 6. Phase V requirements: Battlefield assessment planning graphs

1. Develop frequency histograms for the reservoir drawdown strategy results.

   a. Utilizing the frequency tables generated during the Phase IV analysis, select an appropriate class interval for both the drawdown time and flow rate results. The number of class intervals typically falls between five and twenty and is based on the range of measurements.

   b. Construct a frequency histogram for both drawdown variables plotting the class intervals on the horizontal axis and the respective frequencies on the vertical axis.

   c. Annotate the frequency histogram with the following distribution characteristics: the mean, standard deviation, and quartiles.

2. Develop cumulative frequency distributions for the reservoir drawdown strategy results.

   a. Utilizing the frequency histogram for both drawdown variables, construct cumulative frequency distributions.

   b. Plot cumulative (relative) frequency on the vertical axis and variable range on the horizontal axis.

3. Evaluate the battlefield assessment planning graphs utilizing statistical inferences and relate the resultant probabilities to contingency OPLAN analyses.

distinct formats.

Probability becomes the mechanism for interpreting the reservoir drawdown strategy results and applying these statistical inferences to alternative courses of action during contingency OPLAN analyses; these courses of action reflect the expected responses, under drawdown conditions, rather than educated guesses by the military planner.

The battlefield assessment graphs represent a valuable planning resource for the Army; they are a significant improvement over current drawdown analysis capabilities.

MILITARY BENEFITS OF THE RAMBO CONCEPT

The military benefits of the RAMBO analysis procedures are threefold: (a) the RAMBO concept integrates computer modeling techniques and statistical methods providing a powerful analysis tool, (b) the concept is applicable to contingency OPLAN analysis as well as war gaming simulation studies, and (c) the technique is site independent facilitating its utilization in any military theater of operation.

The current military technique for evaluating reservoir drawdown strategies is limited to graphical and backward step analysis methods. Both procedures assume a linear approximation for reservoir discharge rates; however, they are not physically based and do not account for inflow conditions into the river basin system. Additionally, neither method properly accounts for the interrelationships existing between reservoirs in a complex river system (parallel and tandem operation). These analysis techniques are a poor approximation; at best, they force the military planner to validate contingency planning guidance based on very risky drawdown assessments.

The RAMBO concept provides both the computation and speed benefits associated with computer model simulation techniques. The analysis procedure, incorporating both the physical and hydrologic characteristics associated with reservoir discharge rates, travel times, inflow rates, and diversion/return flow networks, can evaluate any complex river system. The concept enables the military planner to evaluate drawdown times and crossing site flow rates in a probabilistic fashion allowing risk to be factored into the planning process in a quantified sense. Utilizing the RAMBO concept, engineer river crossing assets can be allocated at specific sites based on an expected range of flow rates, while drawdown times can be factored into offensive or defensive planning techniques and force disposition strategies.

The RAMBO procedures have applicability in war gaming simulations (tactical exercises without troops) and military service schools (Command and General Staff College and Army War College). Battlefield assessment planning graphs could be developed for selected theaters of operation enabling military reservoir operations to be incorporated into simulated battlefield war gaming scenarios. This would enable military officers to evaluate the utility of drawdown operations as they relate to both offensive and defensive strategies. Additionally, military service schools could integrate the procedures in classroom training exercises allowing students to evaluate the consequences of alternative reservoir drawdown strategies on battlefield operations.

CHAPTER IV

KOREAN CASE STUDY

HISTORICAL PERSPECTIVE

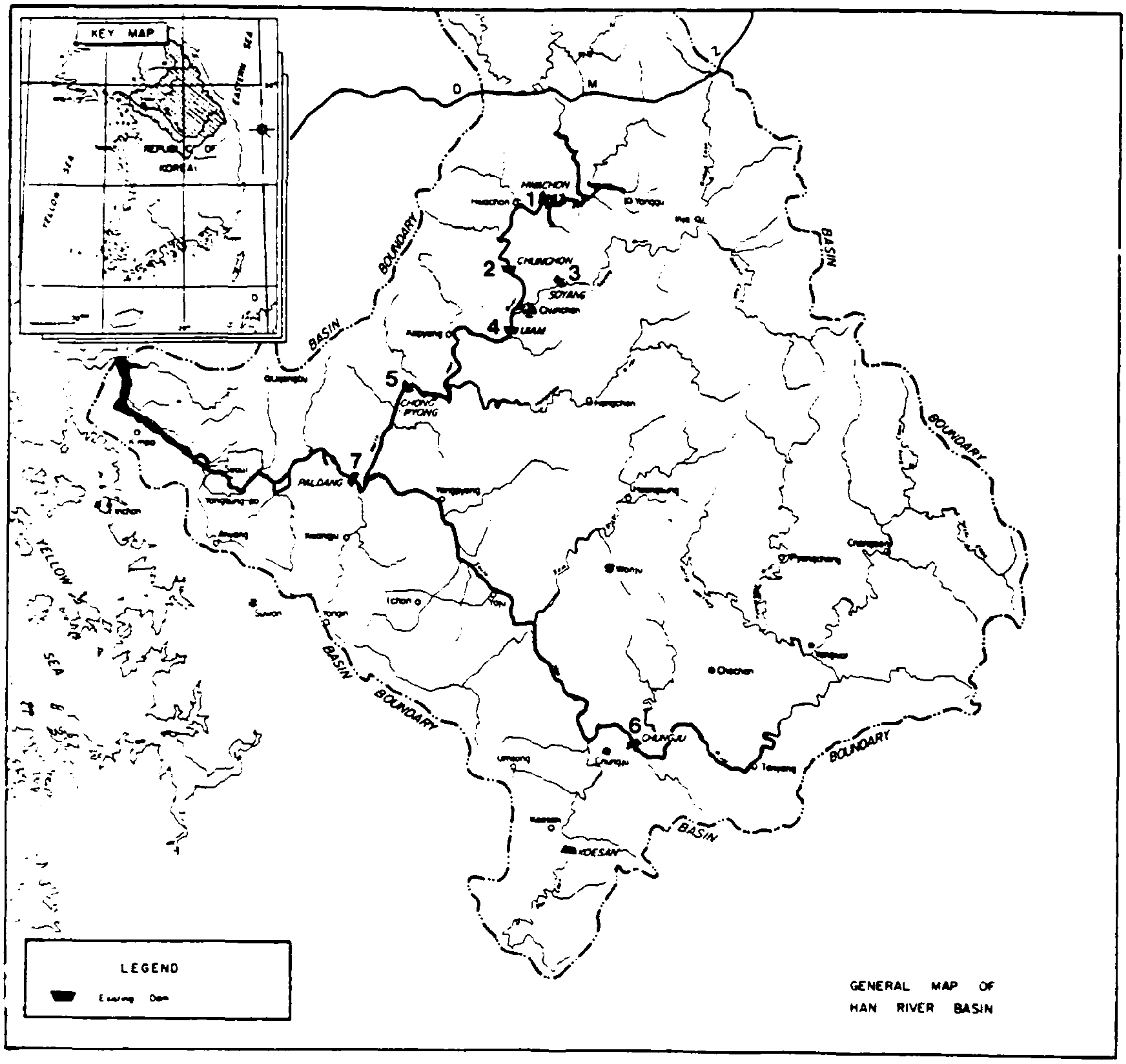
Historically, the Korean Peninsula has been a site of tension and military conflict; the Peninsula remains one of the most heavily armed and fortified regions in the world. Following World War II, the country of Korea was politically divided into two sectors by a joint Soviet-United States commission. Soviet influence on the Peninsula ultimately led to the formalized division of the country in 1947. North Korea chose a Marxist socialism form of government as opposed to that of a parliamentary democracy in South Korea. In 1950 the North invaded the South and attempted to unify the entire Peninsula and place the population under communist rule. The effort was almost successful; however, with the assistance of the United Nations Command the South was able to gain back its lost territory. In 1953, the conflict was hastily brought to a halt with the establishment of an armistice agreement at Panmunjom. Both sides agreed to a cease fire under the supervision of the United Nations, and a military demarcation line was established along with a four-kilometer wide Demilitarized Zone (DMZ) to help foster the cease fire and reduce tensions (Bunge, 1981b).

Since the end of the Korean conflict, the major external threat to South Korea's national security has continued to be communist North Korea. Although the 1953 truce was designed to end hostilities, espionage and hostile provocations have become permanent features of inter-Korean relations. During the past thirty-one years over 354,000 truce violations have been claimed by the two sides indicating that the truce did not signal the end of the conflict between the North and the South.

The possible outbreak of another conflict as well as infiltration, espionage, and sabotage are threats to South Korea and well within the realm of possibility. Throughout the decade of the 1970's and continuing into the 1980's, the North Korean armed forces have remained deployed in an offensive posture despite their claims to the opposite. Military analysts have monitored their defense expenditures and reported that between fifteen and twenty percent of the nation's gross national product is spent on military development. This has led to a military build-up that has approximately doubled the size of the country's ground attack forces, rating them as the fifth largest armed force in the world. North Korea remains self-sufficient in ground armaments and is considered capable of launching a surprise attack that could be sustained for approximately thirty days considering the size of the nation's current military stockpile (Bunge, 1981a).

MILITARY ASSESSMENT

The Han River Basin (HRB) was chosen for the case study because of a strong U.S. commitment to the security of South Korea and the significant hydraulic warfare potential posed by the system of seven reservoirs along the North and South Han Rivers (Figure 12). Under normal conservation operation, the HRB reservoirs maintain approximately 6.4 billion cubic meters of storage volume, with forty percent of this volume contained above the gated spillway levels. Graphic portrayals of the reservoir storage volumes are depicted in



#	Reservoir Name	Max Water Level (M)	Max Water Volume (CM x 1000)	Conservation Water Level (M)	Conservation Volume (CM x 1000)	% of Max Volume Above Spillway	% of Conservation Volume Above Spillway
1	Hwachon	183.0	980000	181.0	905000	33.7	28.2
2	Chunchon	104.9	215000	103.0	150000	82.6	75.1
3	Soyang	198.0	2900000	193.5	2490000	31.4	20.1
4	Uiam	73.4	102254	71.5	80000	99.5	99.3
5	Chongpyong	52.0	203914	51.0	187000	73.0	70.6
6	Chungju	145.0	2625000	141.0	2330000	58.1	52.8
7	Paldang	29.5	430000	25.5	252000	97.5	95.7
		Total	7456168	-----	6394000	48.5	39.9

Figure 12. Map of the Han River Basin, Korea, depicting the seven main reservoirs and their associated storage volumes

Figure 13 with columns representing the associated maximum and conservation volumes listed at the bottom of Figure 12. Spillway levels for each of the seven reservoirs are located in the center of the graph (horizontal line) and serve to highlight the tremendous potential for induced flooding existing in the river basin.

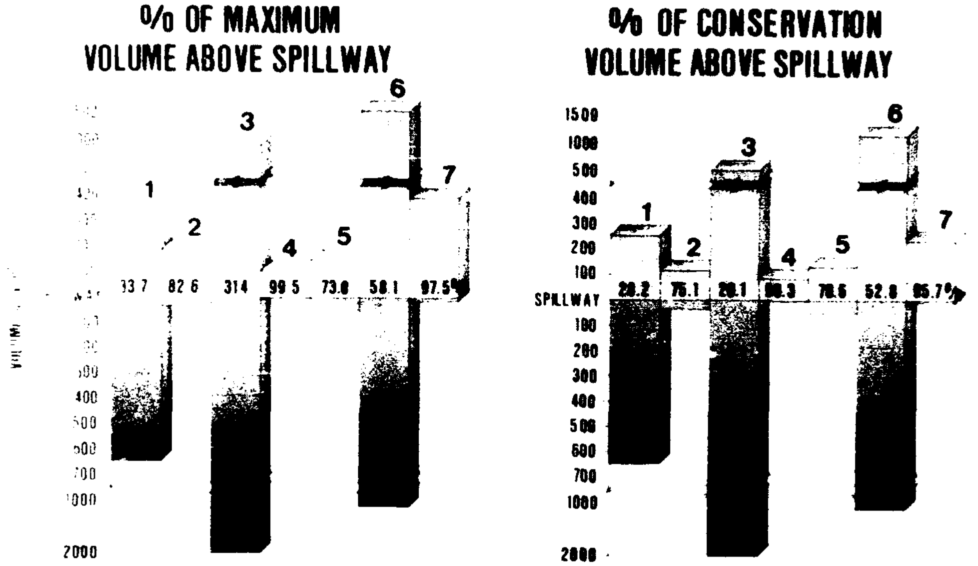


Figure 13. Graphical portrayal of the maximum and conservation storage capacities for the Han River Basin reservoirs.

The complex reservoir system within the HRB must be considered a potential target of a North Korean invasion, because the majority of the U.S. and South Korean armed forces are deployed in the region forward of the North and Lower Han Rivers up to the DMZ. The rear areas throughout this defensive pocket are bordered by the Han River, one of two major water obstacles in the region. Although enemy-induced flooding of the Han River would not impact on mobility or trafficability along the three principal invasion routes into Seoul, the floodwave could be used by North Korea in an attempt to sever lines of communication across the river, flood both military targets and civilian populated areas, damage agricultural lands, and reduce hydroelectric peaking power potential. Any or all of these potential impacts could be overwhelming to South Korea during defensive combat operations.

A defensive measure to preclude this threat consists of drawing down selected reservoirs to safe stages, thus reducing or eliminating the potential impacts of enemy-induced flooding. Six reservoir drawdown strategies were investigated as part of this case study, with analyses focusing on the upper three reservoirs along the North and Soyang Rivers (Hwachon, Chunchon and Soyang), chosen because of their large storage volumes and proximities to the DMZ. The reservoir drawdown scenarios were selected based on a winter attack scenario, covering the time frame from December to February. During the winter period the terrain becomes frozen, enabling armored and mechanized forces to deploy on a wider front.

Forty-one years of historical records were used for the computer model simulations to establish a distribution of drawdown times for each reservoir. These drawdown times were a function of statistically derived inflows and water surface starting elevations, downstream water supply and irrigation withdrawal flows, spillway and conduit rating curves, and specified maximum flow rates at downstream control point locations.

CASE STUDY ANALYSIS

This section describes the application of the RAMBO analysis procedures to the Han River Basin study area. To aid in cross-referencing, the structure of this case study parallels the methodology developed in Chapter III.

Phase I: Military Staff Input

Military Area of Operation

The Area of Operations (AO) selected for the case study is located in the northern section of South Korea. It encompasses the Han River Basin and the lower part of the Imjin River Basin. The terrain is rugged and compartmentalized due to numerous mountain ranges; these topographic features form well-defined avenues of advance throughout the region. Three principal invasion routes exist in the AO, all directed towards the capital city of Seoul. The invasion routes include the Western Corridor, the Central Corridor, and the Chorwon Valley. All three routes represent high speed avenues of advance capable of supporting both mechanized and armor attack forces. Valley walls are steep throughout the region restricting vehicular movement to the valley floor and flood plain areas. Ground surface elevations vary from sea level on the west coast to nearly 1700 meters msl in the Taebaek Mountain Range on the eastern divide. Approximately fifteen percent of the region is cultivated.

The Han River system is the predominant water body within the AO and encompasses 25,944 square kilometers of land area. The Han River consists of a North and South branch with the confluence being approximately ninety kilometers upstream from the mouth of the Imjin River; the main stem then flows through Seoul into the Han River estuary. The area drained by the North Han River equals approximately 10,652 square kilometers or forty-one percent of the drainage basin. The river flows in a south to southwesterly direction from the headwaters in North Korea to the confluence at Paldang Dam. The area drained by the South Han River equals approximately 12,319 square kilometers or about forty-eight percent of the drainage basin. The South Han River flows in a northwesterly direction meeting the North Han at the Paldang Dam. The Lower Han River flows in a west to northwesterly direction from the Paldang Dam to the Han River Estuary. The length of the longest water course within the drainage basin is 488 kilometers (U.S. Army Engineer District, Far East, 1981).

The model study should include the seven major reservoirs along the North and South Han Rivers and the Soyang Tributary (Table 7). Analyses should focus on the upper three reservoirs within the system (Hwachon, Chunchon and Soyang) because of their proximity to the DMZ, large storage volumes, and direct impact on the forward defensive strategies throughout the First and Third ROK Army deployment zones.

Table 7. Reservoirs within the HRB

Reservoir Name	Grid Coordinate	River
Chungju	DR 105955	South Han
Hwachon	CT 932188	North Han
Chunchon	CT 832025	North Han
Soyang	CS 960997	Soyang
Uiam	CS 836878	North Han
Chongpyong	CS 612758	North Han
Paldang	CS 482540	Lower Han

Enemy Capabilities

Ground attack avenues of approach leading from the DMZ to the upper three reservoirs in the river system are both limited and constricted. Although North Korean ground armaments include approximately 2600 tanks and 1000 armored personnel carriers, these routes could not support a major combined attack (mechanized, armor and infantry) capable of capturing the dam control structures rapidly enough to prevent the initiation of South Korean drawdown contingency operations. The dam control structures for Hwachon, Chunchon and Soyang are located approximately twenty-five, forty and forty-one kilometers from the DMZ respectively.

North Korea maintains Special Forces Groups (SFG) specially trained in sabotage, amphibious operations and special warfare. These forces, having an estimated personnel strength between 77,000 and 100,000, are deployed both in North Korean rear areas and along the DMZ. They are capable of conducting air assault (helicopter), airborne (parachute) and glider drop operations. Special forces elements could capture key dam structures under a no-notice scenario, potentially negating a South Korean controlled drawdown contingency operation.

North Korea stations combat fighter units on air bases near the DMZ. These fighter aircraft are considered capable of delivering sufficient munitions to damage gated spillway structures. It is not clear if an enemy attack could be delivered with sufficient force to create induced flooding at downstream locations below the upper three reservoirs.

North Korea maintains approximately 4000-5000 artillery guns and howitzers. Realistically, considering the range of these weapons systems, it is unlikely that precision indirect fire operations could destroy the gated spillway structures on the Hwachon Dam; the other two dams are outside the effective range of these indirect fire weapons.

Induced Flooding Assessment

Thirteen dam-breach scenarios were developed and evaluated for the

HRB reservoir system using a combination of individual and multiple reservoir breaches/releases over a range of initial starting conditions. The analysis focused on the Hwachon and Soyang Reservoirs because of their large storage volumes and proximities to the DMZ. The results indicate that a reservoir drawdown modeling study is warranted to update current reservoir drawdown procedures and to integrate state-of-the-art technologies into theater operational contingency plans.

Reservoir Drawdown Contingency Strategies

Six reservoir drawdown strategies were identified for evaluation (Table 8) based on contingency planning guidance. During reservoir drawdown, Chunchon Dam should be kept at its maximum safe level to maintain the obstacle value of the reservoir. With this one exception, all other downstream reservoirs should serve as reserve storage locations for emergency releases from the upstream dams. The

Table 8. Reservoir drawdown strategies identified for evaluation

- Strategy A - Slow drawdown of the Hwachon Reservoir
- Strategy B - Fast drawdown of the Hwachon Reservoir
- Strategy C - Slow drawdown of the Soyang Reservoir
- Strategy D - Slow drawdown of the Hwachon and Soyang Reservoirs during a simultaneous operation
- Strategy E - Fast drawdown of the Hwachon and Soyang Reservoirs during a simultaneous operation
- Strategy F - Fast drawdown of the Hwachon, Soyang, and Chunchon Reservoirs during a simultaneous operation

reservoirs should fill in order, proceeding in a downstream direction from the DMZ. All downstream reservoirs should continue to meet hydropower, water supply, and irrigation demands during drawdown operations.

Flooding of military facilities, populated areas, and farming regions is not considered acceptable during slow drawdown operations. The specified reservoir(s) must be emptied to the spillway level as quickly as possible, but at the same time, drawn down at a rate that will not impact on activities along the river system. Flow rates can not exceed 5000 cubic meters per second at any specified river crossing site.

Flooding along the river system is considered acceptable during fast drawdown operations. With fast drawdown, the specified reservoir(s) are considered in imminent danger, necessitating the evacuation of all water storage above the spillway level as quickly as possible (up to maximum discharge) without regard for facilities, populated areas, and farming regions throughout the downstream floodplain area. Although fast drawdown strategies are designed to optimize the time required to lower reservoir stages to the spillway water level, river crossing sites must still be operational at all specified locations.

River Crossing Sites

The Indogyo river crossing site (Seoul) will be the only site included in the reservoir drawdown study. The maximum permissible flow rate for this site is 5000 cubic meters per second.

Phase II: Data Collection

Data collection checklists for the HRB drawdown study are included as appendices to this report. These checklists include reservoir (Appendix A), control point (Appendix B), hydropower (Appendix C), time series inflow (Appendix D), and map & basin (Appendix E). The checklists describe the river system in both quantitative and mathematical terms.

Phase III: Computer Model Formulation

Logic Network

A logic network (Figure 14) was created for the HRB which simplified the complex river system into control points (reservoir and non-reservoir), diversion and return flow paths (water supply and irrigation), and river channels (main and tributary). The map and basin checklist (Appendix E) identified both existing and potential irrigable areas within the basin and served as a focal point for locating non-reservoir control points and diversion/return flow paths. All reservoirs within the basin were included in the model study with the exception of the Koesan Dam. This reservoir contains a very limited storage capacity, has no operating spillway, and maintains a generating capacity of only 2.6 megawatts (MW). All control points for the model network were located on the basis of known demands and limiting constraints identified within the river system.

System Hydrology Requirements

System hydrology requirements were identified (streamflow and basin net evaporation) on the basis of historical records maintained by the U.S. Army Corps of Engineers District, Far East. The time series inflow data checklist (Appendix D) provided forty-one years of

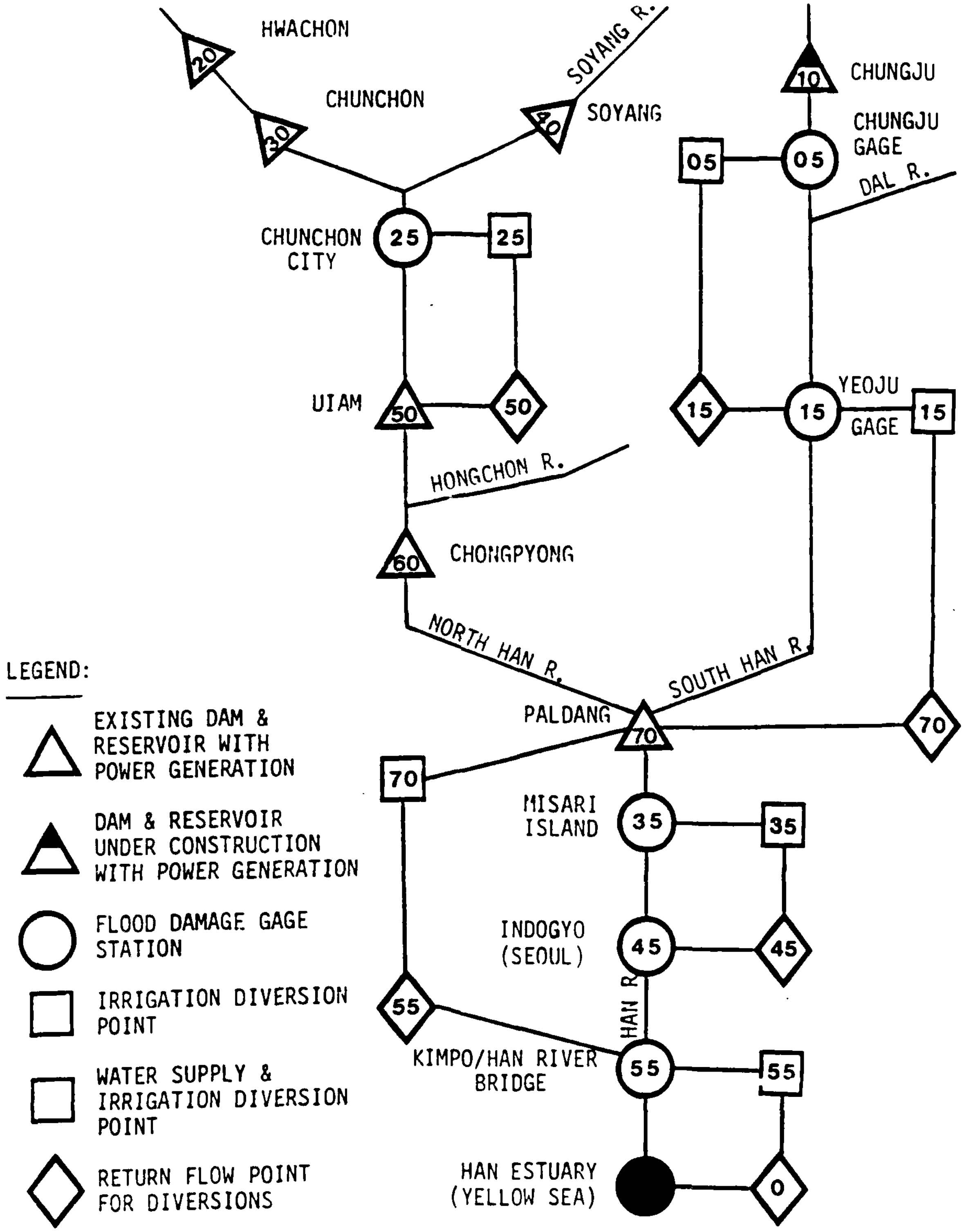


Figure 14. Logic network for the Han River Basin, Korea, depicting river channels, control points, and diversion/return flow paths for the complex river system

historical streamflow records at five gaging locations within the basin (U.S. Army Corps of Engineers Far East District, 1980). These stream flow data allowed a multi-year analysis to be conducted utilizing a fixed monthly time interval. Since the streamflow records represented natural existing flows without the influence of reservoir regulation, the HEC-5 program could automatically calculate the incremental local flows between all control points based on the selection of option twenty on the J3 input card. No routing was required during the base line computer model simulations because of the fixed monthly time interval.

The map and basin checklist identified the monthly net evaporation rates for the HRB. These rates were used in the model's hydrologic balance equation to account for the influence of monthly precipitation and evaporation on the basin's reservoir storage volumes. Both checklists, in conjunction with exhibit 8 of the HEC-5 users manual (input description), were utilized to complete the following input data cards:

(1) J3 - output and flow options (data field 6)

(2) J6 - basin monthly evaporation (data fields 1 thru 12)

(3) BF - beginning of flood (data fields 1 thru 9)

(4) IN - inflows or local flows (data fields 1 thru 14 repeated for 41 years of streamflow records)

Reservoir Characteristics and Operating Criteria

The third step in the model formulation process defines the basic reservoir characteristics and operating rule curves for the river basin. These basic characteristics included (1) capacity-elevation curves, (2) area-elevation curves, (3) combined outlet capacity rating curves, and (4) monthly net evaporation rates. The reservoir checklists (Appendix A) contained all the necessary input data to define the basic features highlighted above for the HRB system. These characteristics are an extremely important element in the modeling process because they define the physical operating features of the reservoir. All storage and release computations throughout the model simulation are based on the interrelationships established between these input data components; some examples include the following: (1) the outlet capacity rating curve determines the maximum possible release at any given reservoir storage level, (2) area-elevation curves along with net evaporation rates are required in order to calculate the total surface evaporation during model simulations, and (3) capacity-elevation curves are necessary during hydropower simulations to calculate available head for power generation.

The operating criteria for all reservoirs was specified utilizing five storage index levels which defined the inactive, buffer, conservation, flood control, and top of dam storage pools. These pool levels determined the appropriate reservoir release rates for each reservoir in the system based on a series of constraint equations and operational priorities defined in the computer code. Reservoir release constraints included (1) low flow conservation operations, (2) minimum release constraint, (3) maximum release constraint, (4) flood control operations, and (5) user specified releases. These constraints determined the type of release that could be made based on the current reservoir operating level. The operational priorities were used in conjunction with the release constraints to keep all reservoirs in balance (all reservoirs at the same index level) throughout the river system. These priorities could be adjusted prior to a model simulation (J2.4 card) based on user designed input selections. Although each reservoir in the HRB was operated to meet specified targets at downstream control points, all releases were a function of the operating level at the beginning of the time period, specified storage index levels (operating rule), reservoir release constraints, and selected operational priorities.

The rule curve option in the HEC-5 model was not used during the HRB model simulations. No data were available to define rule curves for the reservoirs in the system.

The following reservoir input data cards were completed for each of the seven reservoirs modeled in the HRB using the reservoir checklists and Exhibit 8:

(1) RL - target levels (data fields 1 thru 7)

(2) RS - storage capacities (data fields 1 thru 10)

(3) RQ - outlet capacities (data fields 1 thru 10)

(4) RA - areas (data fields 1 thru 10)

(5) RE - elevations (data fields 1 thru 10)

(6) R3 - net evaporation (data fields 1 thru 12)

(7) J1 - storage allocation (data fields 1 thru 9)

(8) J2 - operational parameters (data field 4)

Hydropower Characteristics and Operating Criteria

The fourth step in the model formulation process entails the integration of hydropower plant operating characteristics and at-site power requirements into the input data deck. All seven reservoirs in the HRB were designed to operate for hydropower. Their basic operating characteristics, peaking capability, and monthly at-site power requirements are included in the completed hydropower checklist (Appendix C). Basic powerplant operating characteristics include (1) installed generating capacity, (2) overload ratio, (3) powerplant efficiency, (4) penstock discharge capacity, (5) fixed head loss, and (6) average tailwater elevation. Maximum power generation for each reservoir is limited by the overload ratio and generating capacity, while maximum power release is limited by the penstock discharge capacity. The hydropower release priority established for the model simulations insured that primary power releases would be made as long as reservoir storage levels were above the inactive pool level. Additionally, if flooding was occurring at any downstream location, power releases would not be allowed that would contribute to that flooding. In all cases, if sufficient storage existed to allow the proper hydropower release and this release did not violate any constraints or operational priorities, then this release would represent the minimum required flow for that reservoir during the time period.

The following hydropower input data cards were completed for each of the seven reservoirs modeled in the HRB using the hydropower checklist and Exhibit 8:

(1) P1 - powerplant characteristics (data fields 1 thru 8)

(2) P2 - second hydropower card (data fields 1 thru 2)

(3) PR - hydropower energy requirements (data fields 1 thru 14)

(4) PQ - hydropower releases (data fields 1 thru 10)

(5) PT - hydropower tailwater (data fields 1 thru 10)

(6) PP - hydropower peaking capability (data fields 1 thru 10)

(7) PS - hydropower storage versus head (data fields 1 thru 10)

(8) PE - hydropower efficiency versus storage (data fields 1 thru 10)

Control Point Characteristics

In the fifth step of the process, control point characteristics (demands, channel capacities, area ratio factors, and minimum required/desired flow rates) are incorporated into the input data logic network. These characteristics establish constraints and target values throughout the river system and are used by the program to operate reservoirs and regulate streamflow rates. Non-reservoir control points were established on the basis of three constraints: (1) maximum nondamaging flow, (2) minimum required flow, and (3) minimum desired flow. These limiting conditions determined both the acceptable upper and lower limits for streamflow rates during model simulations. Reservoir control points were limited by two constraints: (1) maximum nondamaging flow rates, and (2) hydropower releases. Minimum required and desired flows for all reservoirs were met if reservoir releases satisfied monthly hydropower requirements. Water supply and irrigation demands were specified for one reservoir and five non-reservoir control points within the network and were based on monthly forecast schedules compiled for the HRB.

The control point checklist provided all the necessary data to complete the following input cards for the HEC-5 model:

(1) CP - control point card (data fields 1 thru 6)

(2) IN - identification card (data fields 1 thru 4)

(3) C1 - area ratio factor (data fields 1 thru 4)

(4) DR - diversion data for control point (data fields 1 thru 9)

(5) QD - diversion flows (data fields 1 thru 13)

(6) QM - minimum desired flows which vary monthly (data fields 1 thru 12)

Reservoir Operation Points

The final step in the model formulation process incorporates the downstream control point operating policy into the model network. The reservoir operation points selected for the HRB system were identified on the basis of two factors: (1) reservoir purposes and (2) control point demands (flood control channel capacity and minimum required/desired flows). The Chungju and Soyang multipurpose reservoirs were both constructed to meet water supply, irrigation, and flood control demands at downstream locations; they represent the only multipurpose reservoirs in the river basin. Chungju reservoir was designated to operate for non-reservoir control points 05 and 15, while Soyang reservoir was specified to operate for non-reservoir control point 25. Both reservoirs were designated to operate for reservoir control point 70 (Paldang Dam) since this reservoir provides eighty percent of the water supply for Seoul. The Soyang Dam was allowed to operate through two downstream reservoirs (Uiam and Chongpyong) because neither of these reservoirs operated with a flood control storage pool. The Paldang Reservoir was operated to meet all demands at non-reservoir control points 35, 45, and 55 along the Lower Han. The three run-of-the-river hydropower reservoirs (Chunchon, Uiam, and Chongpyong) and the Hwachon reservoir were not designated to operate for any downstream control points since their only function was to meet at-site power demands. All reservoir operation points were input using the RO card.

Phase IV: Reservoir Drawdown Analysis

Model Verification

The HRB model simulations were based on a multi-reservoir system operating strategy that included a mixture of both parallel and tandem reservoir subsystems. The model was operated to meet water supply, irrigation, and hydropower demands at thirteen control points in the basin. Model checks were made to (a) insure that the input data deck was set up properly and contained the proper job control cards, (b) insure that the computer-generated natural and incremental local flow values were reasonable and accurate, and (c) verify that the computed reservoir minimum and maximum stage levels did not exceed specified limits during model simulations. Problems were discovered in the computation sequence used to determine the minimum and maximum reservoir stage levels. The HEC-5 program (January 1985 version) allowed HRB reservoir stage levels to exceed surcharge storage capacities resulting in overtopping flow conditions. These programming errors were corrected by the Hydrologic Engineering Center in August 1985. Reservoir stage levels and natural/incremental local flow values, checked with the corrected program code, were both reasonable and consistent with expected results. At this juncture the HRB reservoir system model was classified fully operational.

Base Line Operating System

Because historical reservoir stage levels were not available for the HRB, the HEC-5 program was utilized to simulate these values based on forty-one years of measured streamflow data. Twelve operating strategies were evaluated based on the criteria that they maximize system hydropower production while minimizing water supply shortages over the historical period of record. The strategy providing the optimal results was selected as the base line system; this strategy is included as Appendix F.

Starting Reservoir Storage Volumes

The analysis period selected for the HRB reservoir drawdown study was based on a winter time frame (December, January, and February) because of the favorable trafficability conditions occurring throughout the basin which would tend to support a large-scale mechanized North Korean offensive. The reservoir storage volumes generated with the base line system were averaged over this three-month period (forty values for each reservoir) utilizing the Symphony program. The spreadsheet option of this program provided easy data entry and manipulation facilitating the analysis process. Table 9 represents the starting reservoir storage volume matrix developed for the HRB case study. This matrix depicts the average simulated storage volumes for each reservoir in the basin based on a winter season and a forty-one year historical record. These storage values will be used to simulate the starting water surface elevation in each HRB reservoir during the subsequent drawdown analysis.

Table 9. Starting reservoir storage volumes for the HRB
(All storage volumes are in cubic meters x 10^3)

Reservoir Name and Control Point Number

Year	Chungju CP 10	Hwachon CP 20	Chunchon CP 30	Soyang CP 40	Uiam CP 50	Chongpyg CP 60	Paldang CP 70
1	849999	668101	89821	1770620	22642	105000	256000
2	1173454	561308	89821	1198423	22642	105000	256000
3	1139095	308251	89821	650001	22642	105000	244000
4	1497729	779905	89821	1137114	22642	119819	262000
5	1295969	277000	89821	650001	22642	105000	244000
6	1591763	710940	89821	1239372	22642	107151	257250
7	1594652	747787	89821	1188286	26644	121145	256000
8	510000	277000	89821	782604	41761	132333	244000
9	2189295	901952	89821	2331619	23318	156246	262000
10	2195840	880554	91011	2361151	41761	150096	262000
11	2135942	768151	89821	2476182	22642	105000	256000
12	1935188	504383	89821	2418910	32265	105311	256000
13	1406367	667771	89821	1828951	24710	136943	262000
14	1809965	713520	89821	1637605	22642	120662	262000
15	2296817	877561	89821	2399491	23050	154379	262000
16	2154020	901710	97797	2077364	78640	187000	262000
17	2034263	822093	89821	2394245	41761	129971	256000
18	2182454	821286	89821	2343039	22642	113601	262000
19	1775112	715543	89821	2064979	22642	108175	262000
20	2395175	888133	119087	2580583	41761	177795	262000
21	2027533	833651	89821	2290130	22642	114241	262000
22	1965290	594238	89821	2400156	41761	121852	256000
23	510000	277000	89821	1380849	67631	176004	250000
24	1694322	832881	89821	2232847	22642	105000	256775
25	1422973	653027	89821	2185777	22642	105000	256000
26	1600317	596163	89821	2155645	22642	105000	256000
27	2295720	843417	89821	2349235	22642	135257	262000
28	1877999	791498	89821	2271422	22642	105000	262000
29	1565893	666651	89821	1942283	22642	106326	256000
30	2182675	870519	99817	1923315	71811	187000	262000
31	1684261	747002	89821	2272198	22642	105000	256000
32	1534968	502052	89821	1926732	22642	105000	256000
33	1751058	741876	89821	2368578	22642	105000	256000
34	1580339	651167	89821	2092851	22642	105000	256000
35	2068346	733395	89821	2314521	22642	105000	262000
36	1678469	661343	89821	1938181	22642	131341	262000
37	1464560	859442	94343	2284576	24331	187000	262000
38	1704252	550465	89821	2407601	22642	105000	256000
39	1823477	807852	89821	2325017	22642	105000	256000
40	1892970	764741	89821	2383681	41761	132333	256000

Drawdown Time and Crossing Site Flow Rate Analysis

Computer-simulated reservoir drawdown operations can be considered analogous to a specially designed flood control study. The reservoir(s) selected to be drawn down can be forced into a flood control evacuation mode by repositioning the top of conservation storage index level (TOC) to the spillway crest elevation; any storage volume above the TOC will automatically be released based on reservoir operation criteria and priority release conditions defined in the HEC-5 program. Under these criteria and release priorities the model will evacuate this storage volume (now considered in the flood pool) as quickly as possible without exceeding designated channel capacities at downstream locations (river crossing sites).

Utilizing the reservoir storage values in Table 9 as the initial conditions throughout the basin, the river crossing criteria established at the Indogyo site, and the appropriate drawdown strategy (slow or fast release constraint), computer model simulations were conducted for each year in the historical record to establish a statistical data base of drawdown times and crossing site flow rates. This procedure was repeated for each of the six reservoir drawdown strategies defined in Table 8, requiring a total of 193 simulations to complete the analyses. Detailed drawdown results for the HRB study will be presented in the next two sections.

Statistical Analysis of Reservoir Drawdown Results

The SAS program (Proc Univariate option) was utilized to statistically evaluate the drawdown results for each of the six strategies. The statistical analysis for both the drawdown time and crossing site flow rate results are depicted below in Tables 10 and 11, respectively. These values along with the frequency tables provided by the SAS program were used to develop the battlefield assessment planning graphs in the next section.

Table 10. Statistical analysis of drawdown time results (all times are displayed in hours)

	Strategy A Hwachon (slow)	Strategy B Hwachon (fast)	Strategy C Soyang (slow)
Mean	67.05	57.85	111.30
Std Dev	53.69	43.37	99.29
Skewness	- 0.06	- 0.04	0.07
Quartiles			
Q1 (25%)	1.0	1.0	0.0
Q2 (50%)	78.0	78.0	128.0
Q3 (75%)	113.5	96.0	201.5
Q4 (100%)	146.0	110.0	310.0

	Strategy D (both slow)		Strategy E (both fast)		Strategy F (all fast)		
	Hwachon	Soyang	Hwachon	Soyang	Hwachon	Soyang	Chunchon
Mean	67.05	111.30	57.85	83.73	57.85	83.73	81.75
Std Dev	53.69	99.29	43.37	69.71	43.37	69.71	37.56
Skewness	- 0.06	0.07	- 0.36	- 0.26	- 0.36	- 0.26	- 0.35
Quartiles							
Q1 (25%)	1.0	0.0	1.0	0.0	1.0	0.0	36.0
Q2 (50%)	78.0	128.0	78.0	117.0	78.0	117.0	102.0
Q3 (75%)	113.5	201.5	96.0	147.5	96.0	147.5	114.0
Q4 (100%)	146.0	310.0	110.0	172.0	110.0	172.0	126.0

Table 11. Statistical analysis of crossing site flow rate results (all flow rates are displayed in cubic meters/second)

	Strategy A	Strategy B	Strategy C
Mean	413.30	614.56	544.90
Std Dev	366.61	957.00	374.56
Skewness	1.76	3.32	0.83
Quartiles			
Q1 (25%)	198.7	198.7	176.5
Q2 (50%)	302.5	303.5	651.0
Q3 (75%)	309.0	309.7	785.0
Q4 (100%)	1620.0	5002.0	1680.0

Table 11. Continued

	Strategy D	Strategy E	Strategy F
Mean	780.40	1394.17	2068.57
Std Dev	561.83	1343.74	1777.47
Skewness	0.48	0.97	0.46
Q1 (25%)	248.2	248.2	305.2
Q2 (50%)	820.5	1112.5	1970.5
Q3 (75%)	1156.0	2114.0	3458.0
Q4 (100%)	2215.0	5002.0	5002.0

Phase V: Battlefield Assessment Planning Graphs

The battlefield assessment planning graphs represent the end products of the RAMBO analysis procedures. They graphically summarize the reservoir drawdown strategy results in a statistical framework allowing probability interpretations to be incorporated into the military decision-making process. The statistical distribution for each of the drawdown variables in the HRB study represents only a sample (40 values) of the total population. The concept of statistical inference enables assumptions about the total population to be drawn based on information contained in these sample sets. Based on Tables 10 and 11 above and the frequency tables generated by the SAS program, frequency histograms and cumulative frequency distributions were developed for both variables (drawdown time and crossing site flow rate) for each of the six reservoir drawdown strategies. The battlefield assessment planning graphs for each drawdown strategy are depicted in Figures 15 through 30.

The military planner can utilize these graphical products to incorporate reservoir drawdown contingency planning into the OPLAN analysis process. As an example, Figures 15 and 16 represent the results for Reservoir Drawdown Strategy A (slow drawdown of Hwachon

Reservoir). From these planning graphs the military staff officer could infer that the expected drawdown time, i.e. the mean, for Hwachon Reservoir in any given year (under a winter attack scenario) would be 67 hours and the resultant flow conditions at the Indogyo crossing site would be 413 cubic meters per second. He could also infer that there is a 75% probability that the drawdown time will be less than 113.5 hours. The staff officer could use this information to forecast engineer equipment requirements at particular crossing sites and establish force dispositions to defend against capture of key dams during drawdown operations.

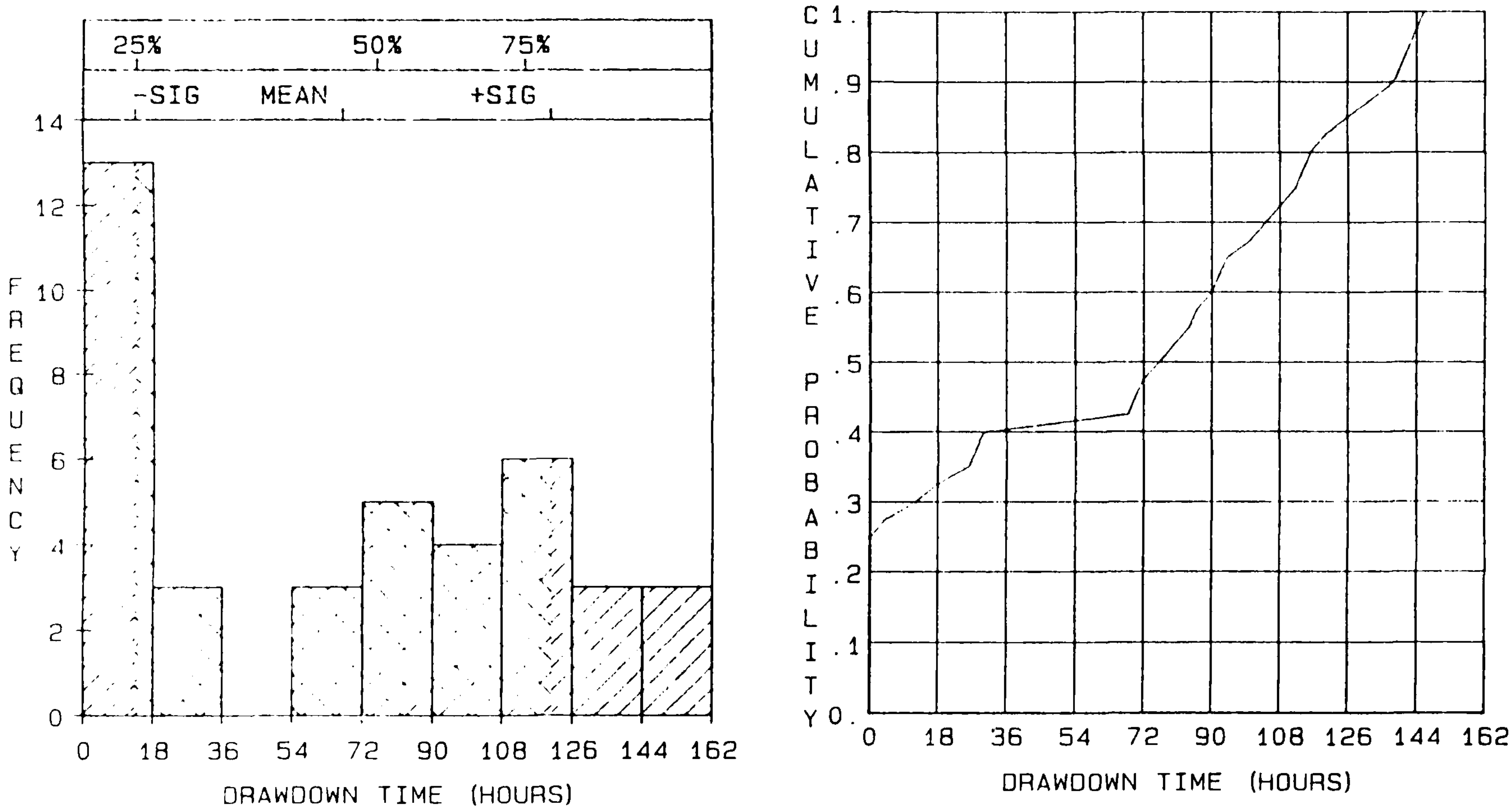


Figure 15. Battlefield assessment planning graphs for Reservoir Drawdown Strategy A (slow drawdown of Hwachon Reservoir) depicting drawdown times for Hwachon Dam, frequency histogram (left) and cumulative frequency distribution (right)

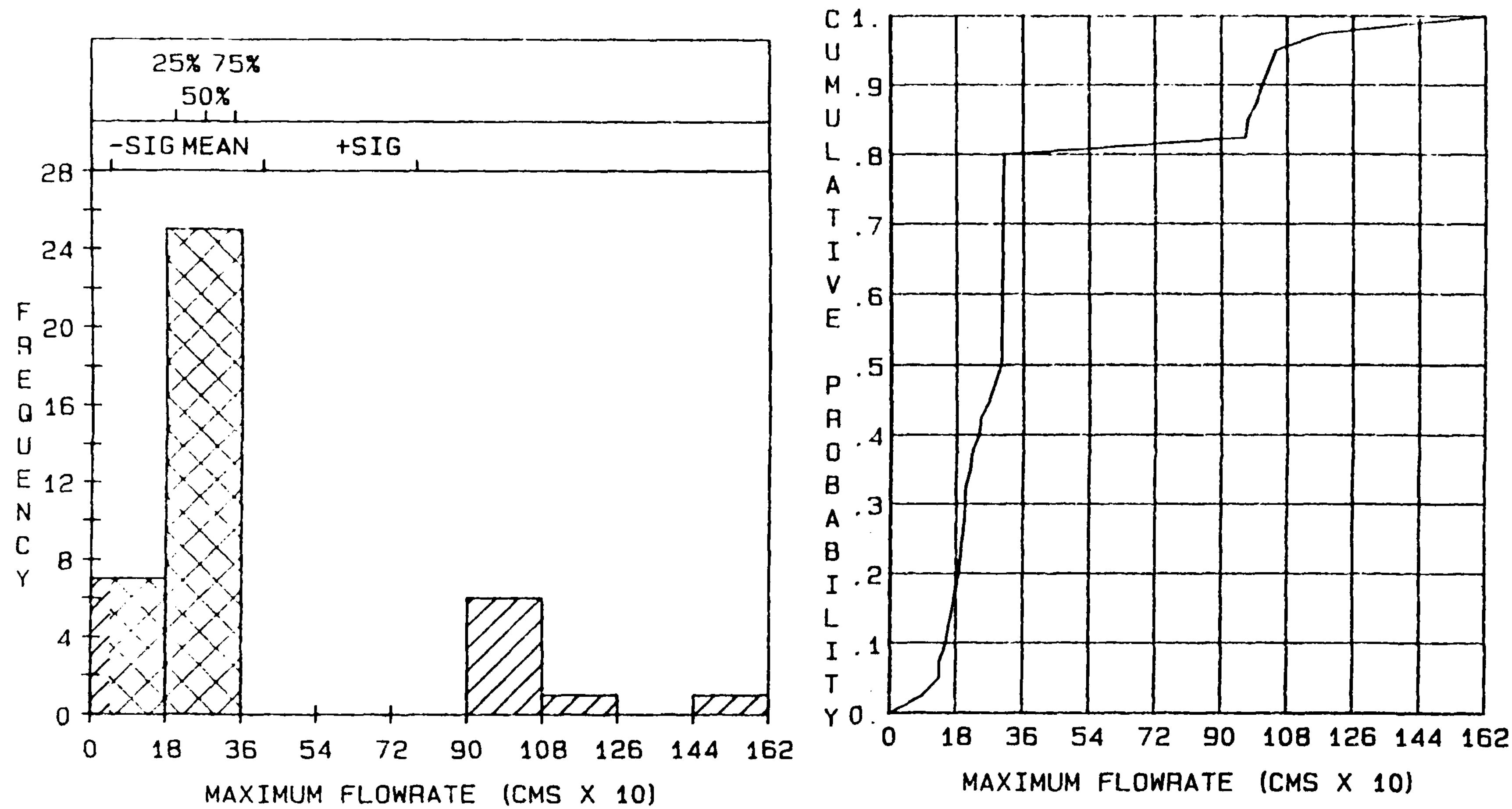


Figure 16. Battlefield assessment planning graphs for Reservoir Drawdown Strategy A (slow drawdown of Hwachon Reservoir) depicting crossing site flow rates for Indogyo, frequency histogram (left) and cumulative frequency distribution (right)

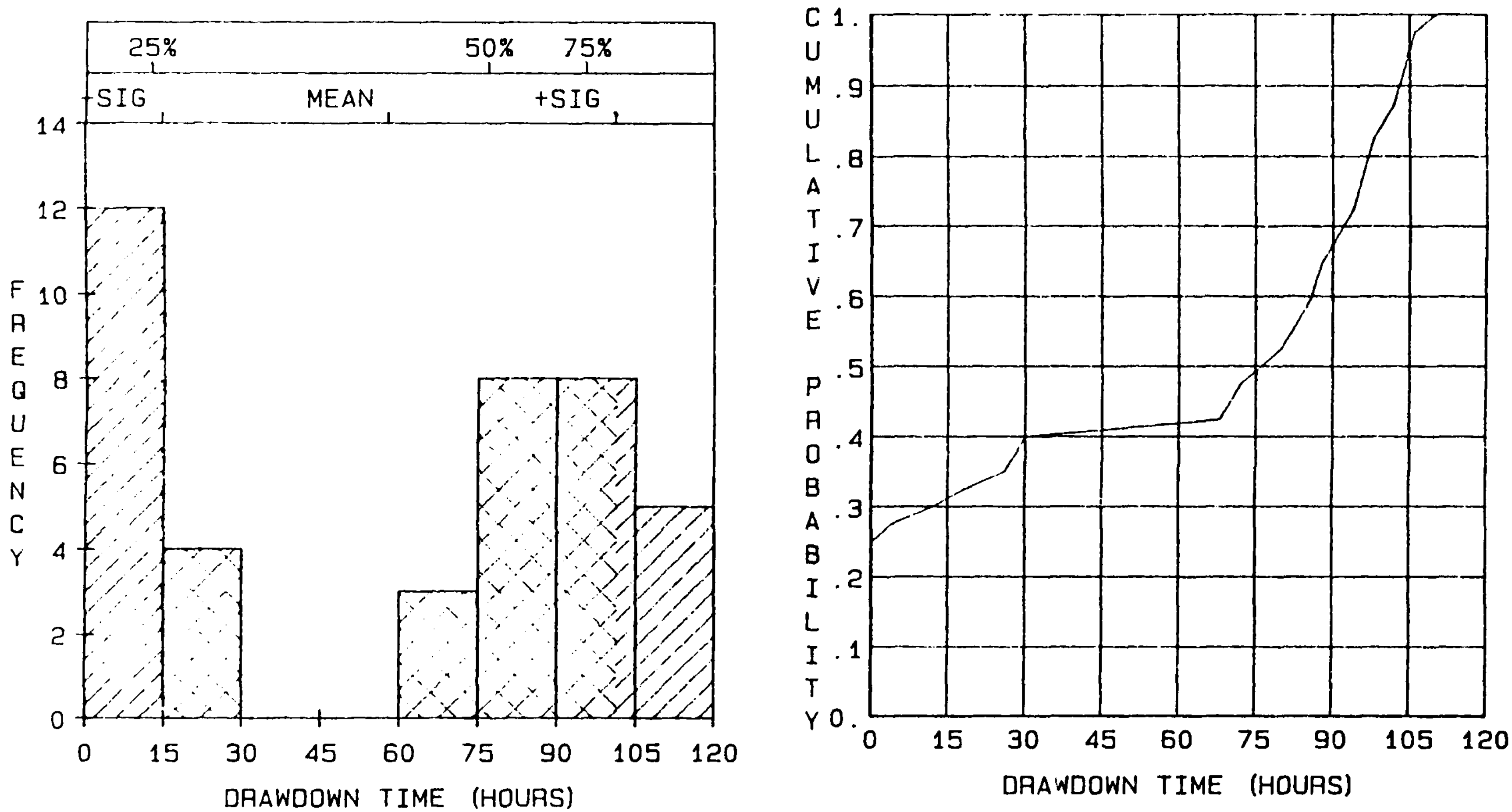


Figure 17. Battlefield assessment planning graphs for Reservoir Drawdown Strategy B (fast drawdown of Hwachon Reservoir) depicting drawdown times for Hwachon Dam, frequency histogram (left) and cumulative frequency distribution (right)

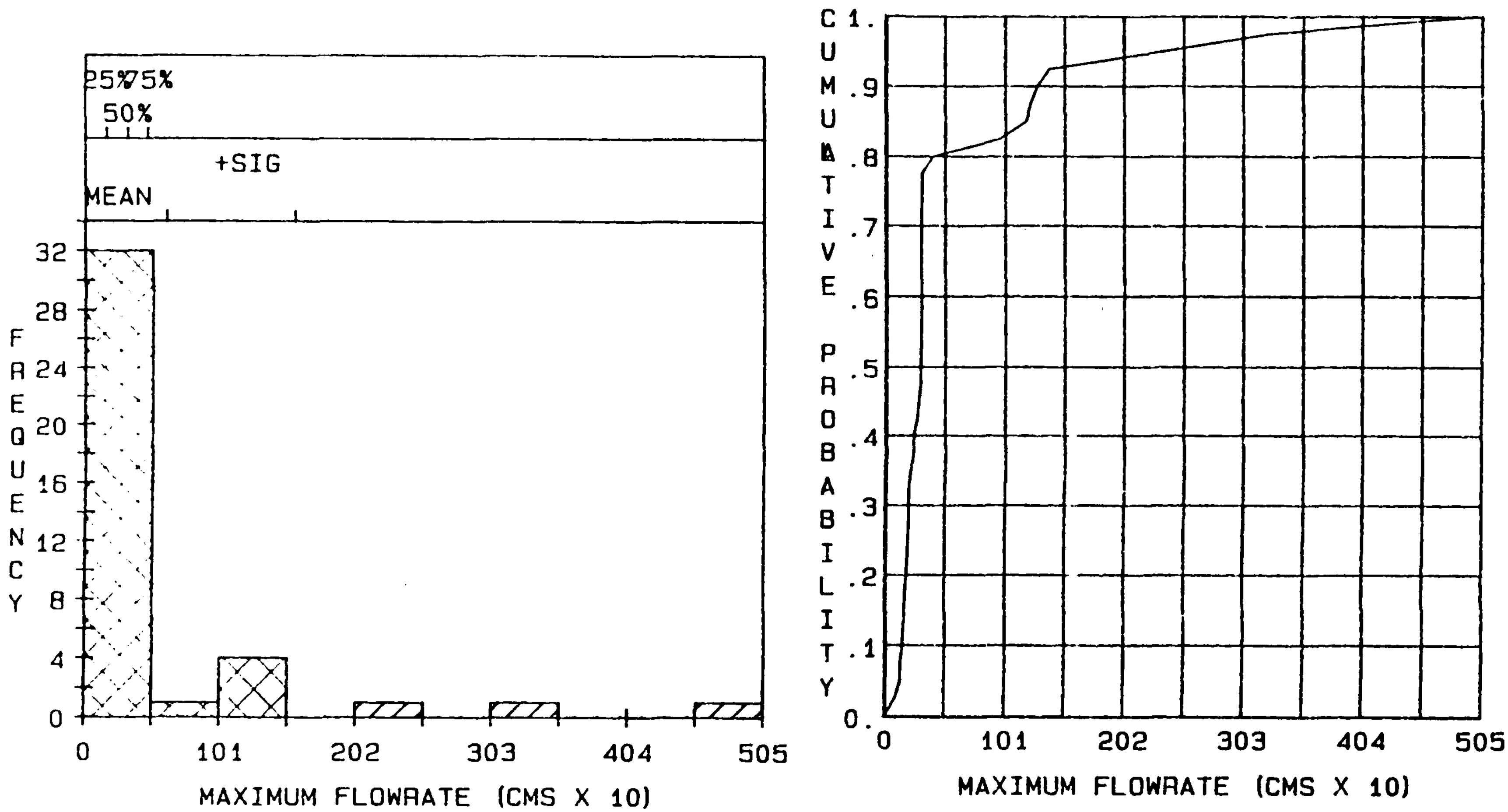
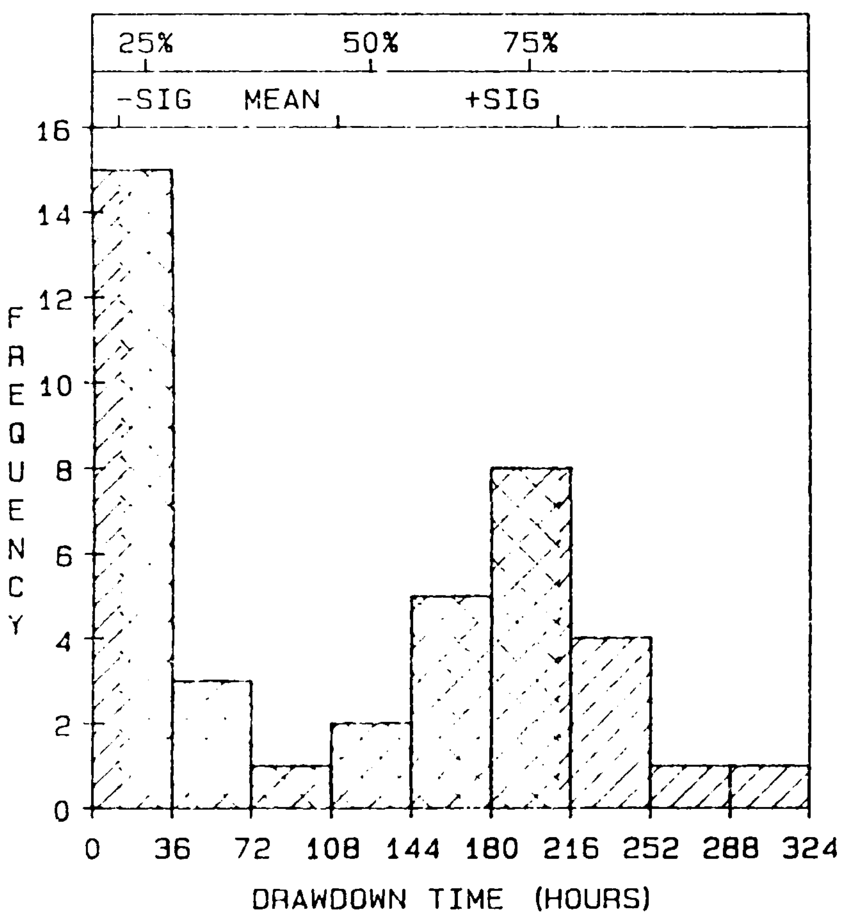


Figure 18. Battlefield assessment planning graphs for Reservoir Drawdown Strategy B (fast drawdown of Hwachon Reservoir) depicting crossing site flow rates for Indogyo, frequency histogram (left) and cumulative frequency distribution (right)



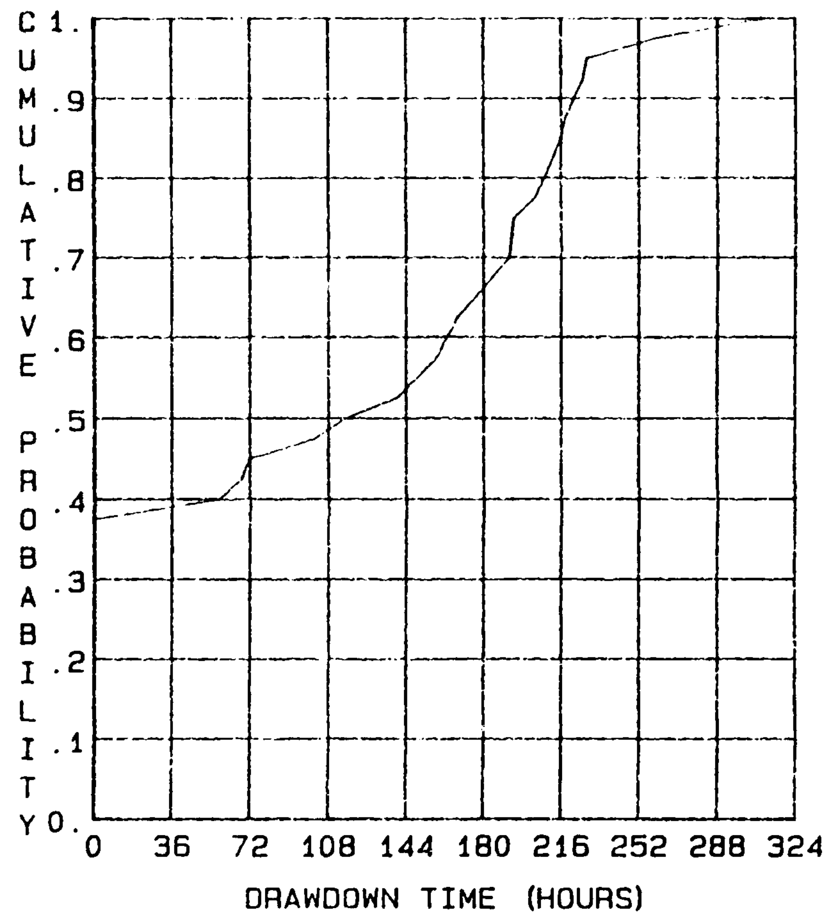
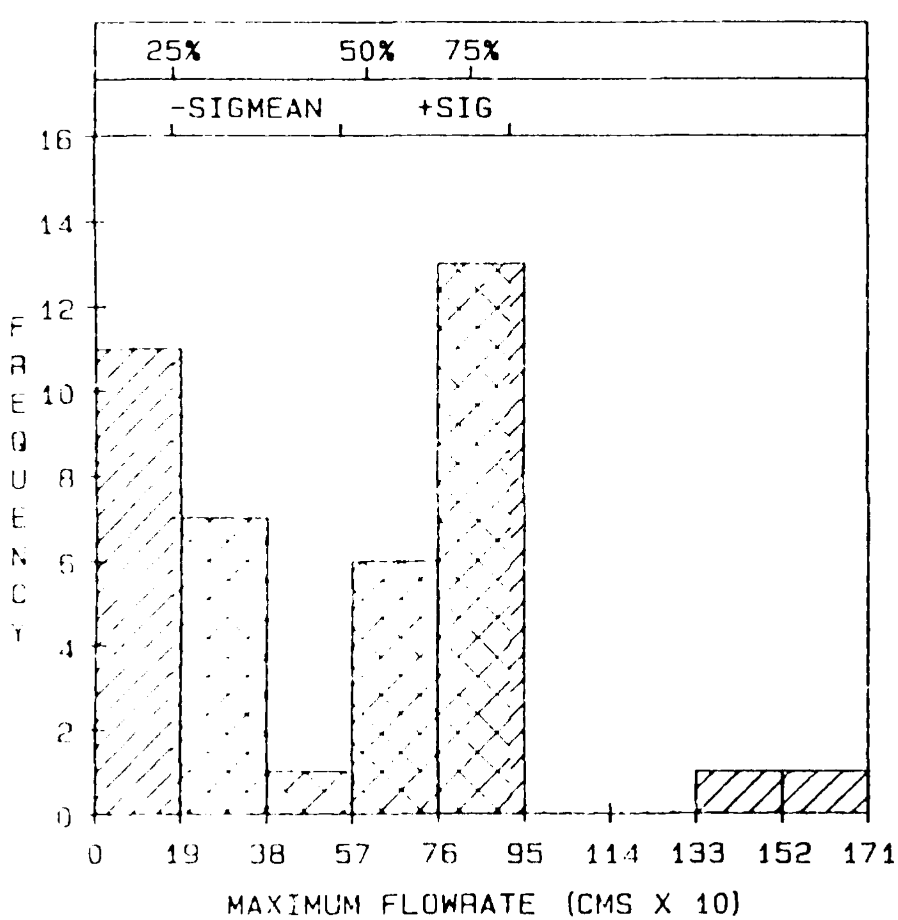


Figure 19. Battlefield assessment planning graphs for Reservoir Drawdown Strategy C (slow drawdown of Soyang Reservoir) depicting drawdown times for Soyang Dam, frequency histogram (left) and cumulative frequency distribution (right)



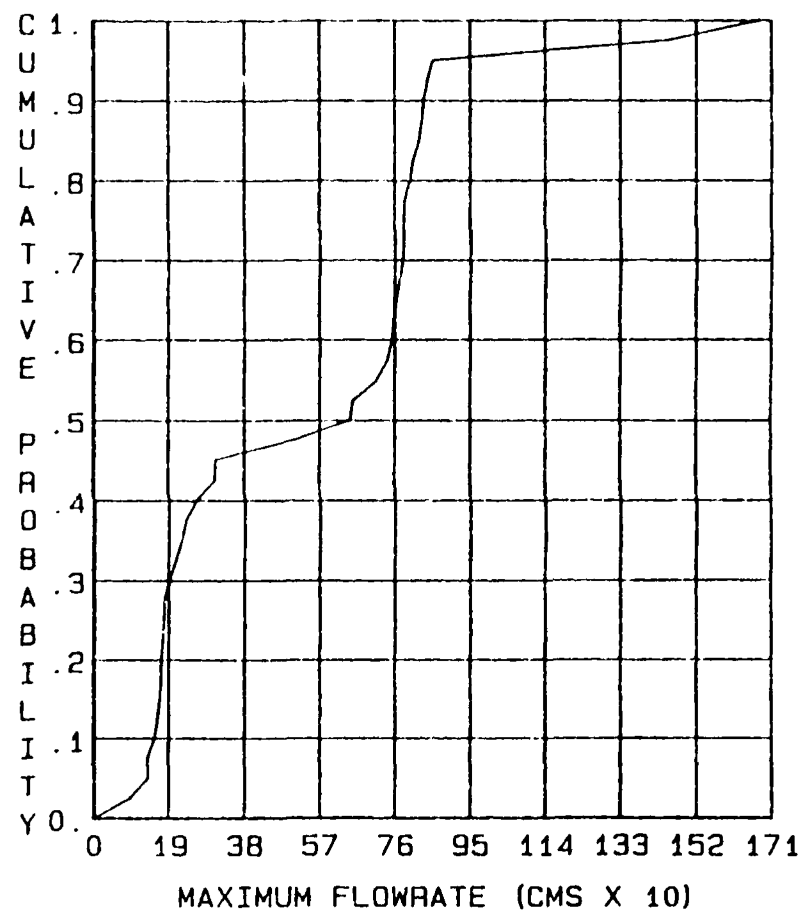


Figure 20. Battlefield assessment planning graphs for Reservoir Drawdown Strategy C (slow drawdown of Soyang Reservoir) depicting crossing site flow rates for Indogyo, frequency histogram (left) and cumulative frequency distribution (right)

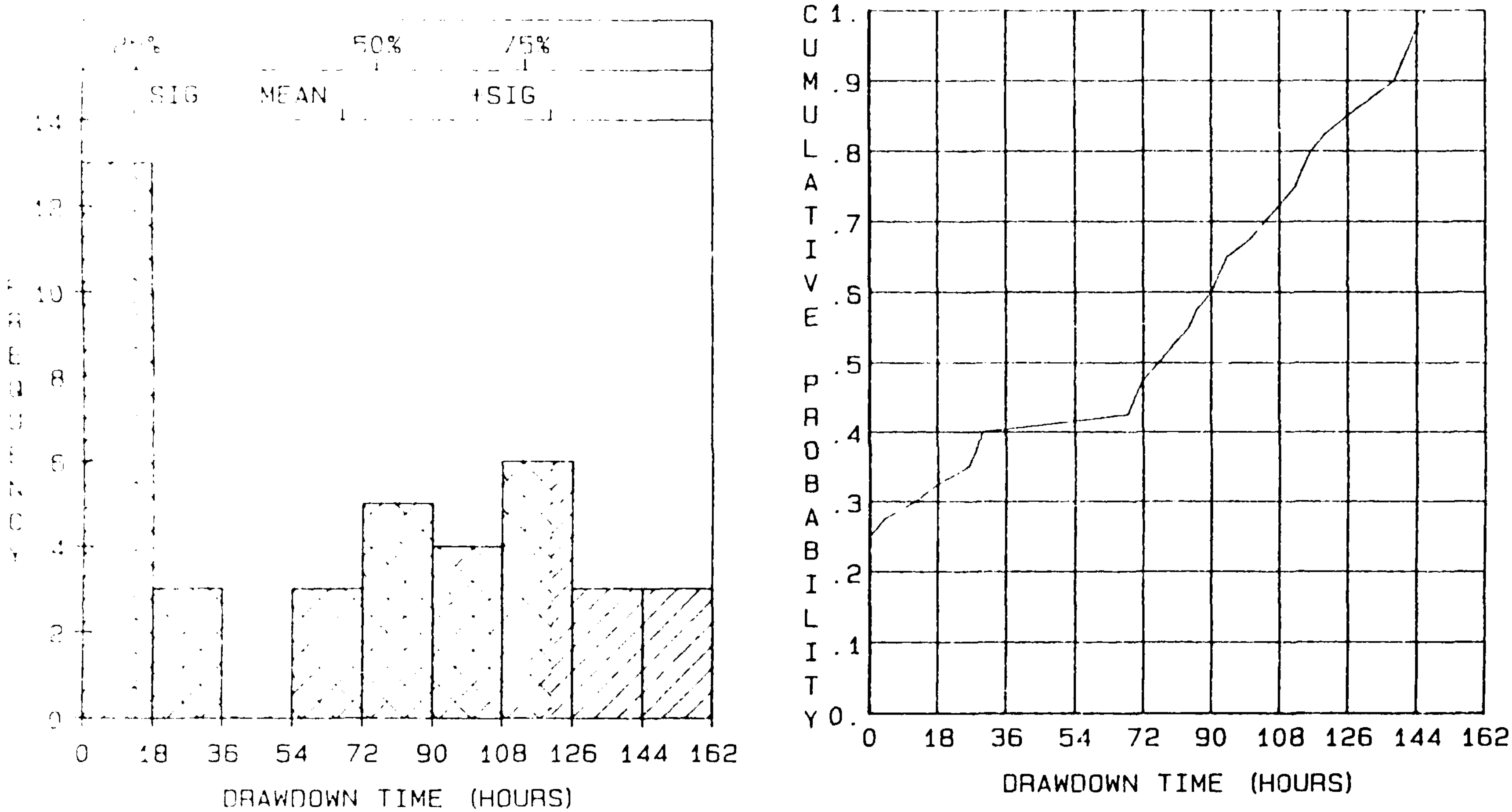


Figure 21. Battlefield assessment planning graphs for Reservoir Drawdown Strategy D (slow drawdown of Hwachon and Soyang Reservoirs during a simultaneous operation) depicting drawdown times for Hwachon Dam, frequency histogram (left) and cumulative frequency distribution (right)

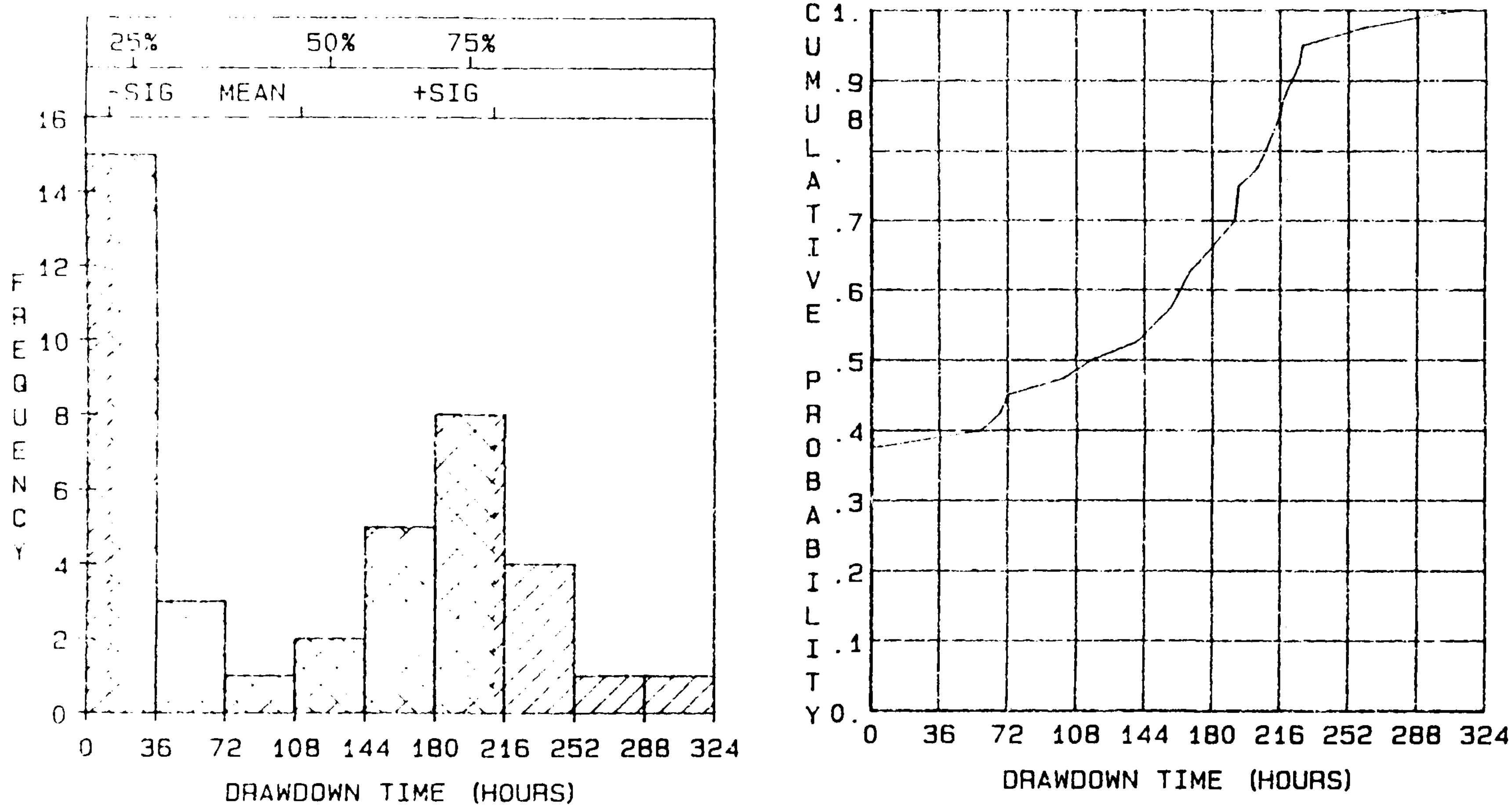


Figure 22. Battlefield assessment planning graphs for Reservoir Drawdown Strategy D (slow drawdown of Hwachon and Soyang Reservoirs during a simultaneous operation) depicting drawdown times for Soyang Dam, frequency histogram (left) and cumulative frequency distribution (right)

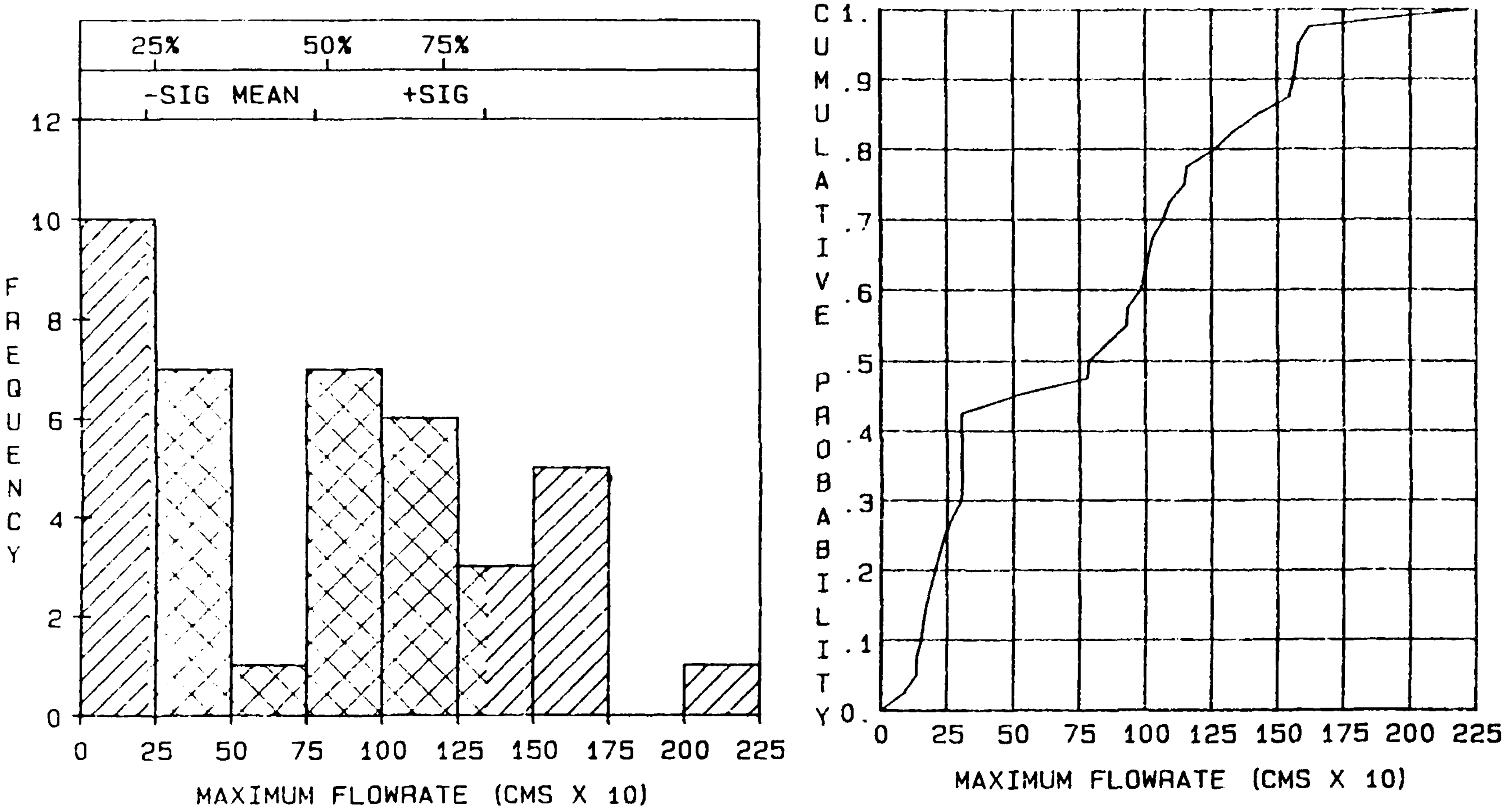


Figure 23. Battlefield assessment planning graphs for Reservoir Drawdown Strategy D (slow drawdown of Hwachon and Soyang Reservoirs during a simultaneous operation) depicting crossing site flow rates for Indogyo, frequency histogram (left) and cumulative frequency distribution (right)

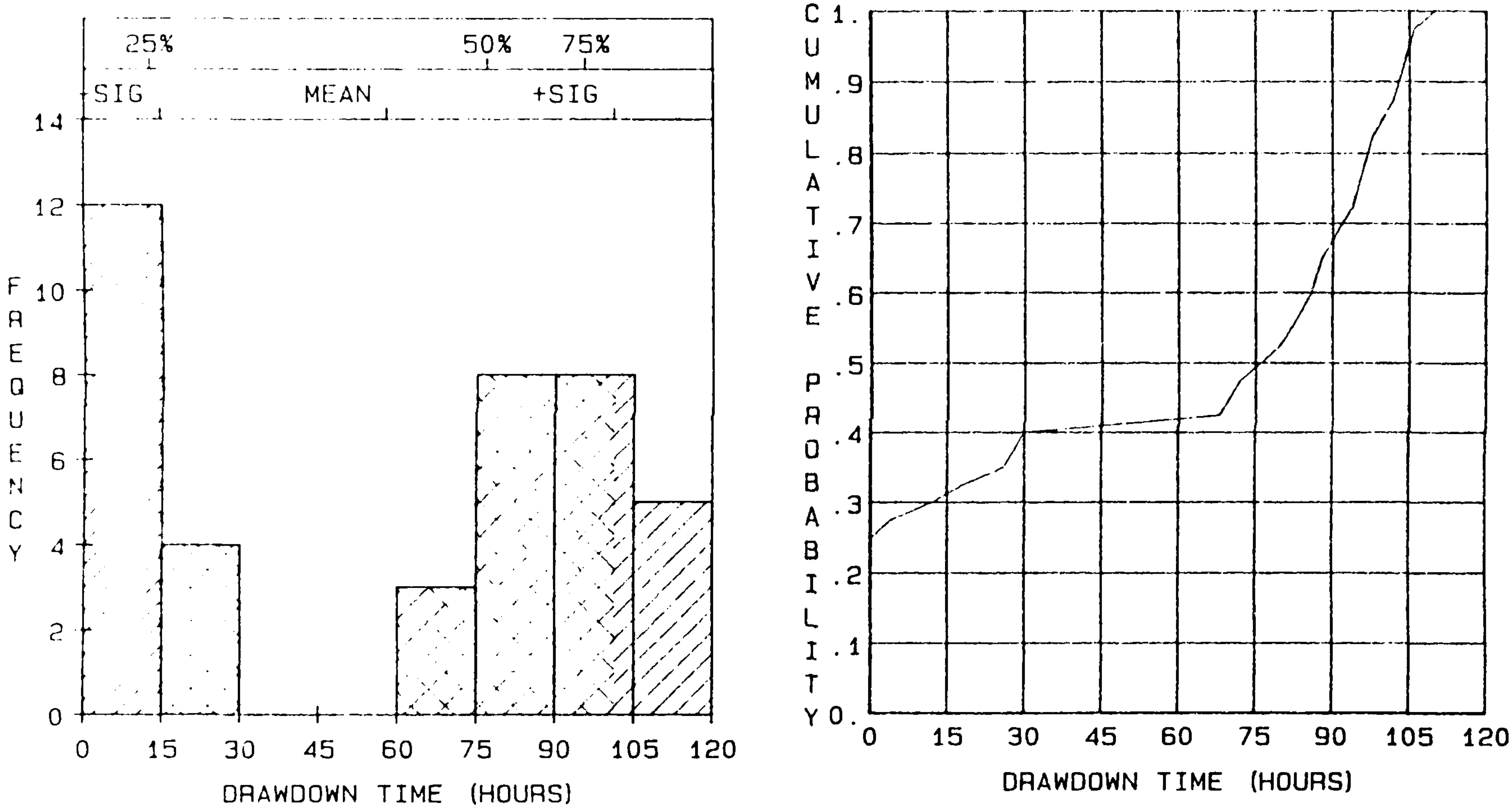


Figure 24. Battlefield assessment planning graphs for Reservoir Drawdown Strategy E (fast drawdown of Hwachon and Soyang Reservoirs during a simultaneous operation) depicting drawdown times for Hwachon Dam, frequency histogram (left) and cumulative frequency distribution (right)

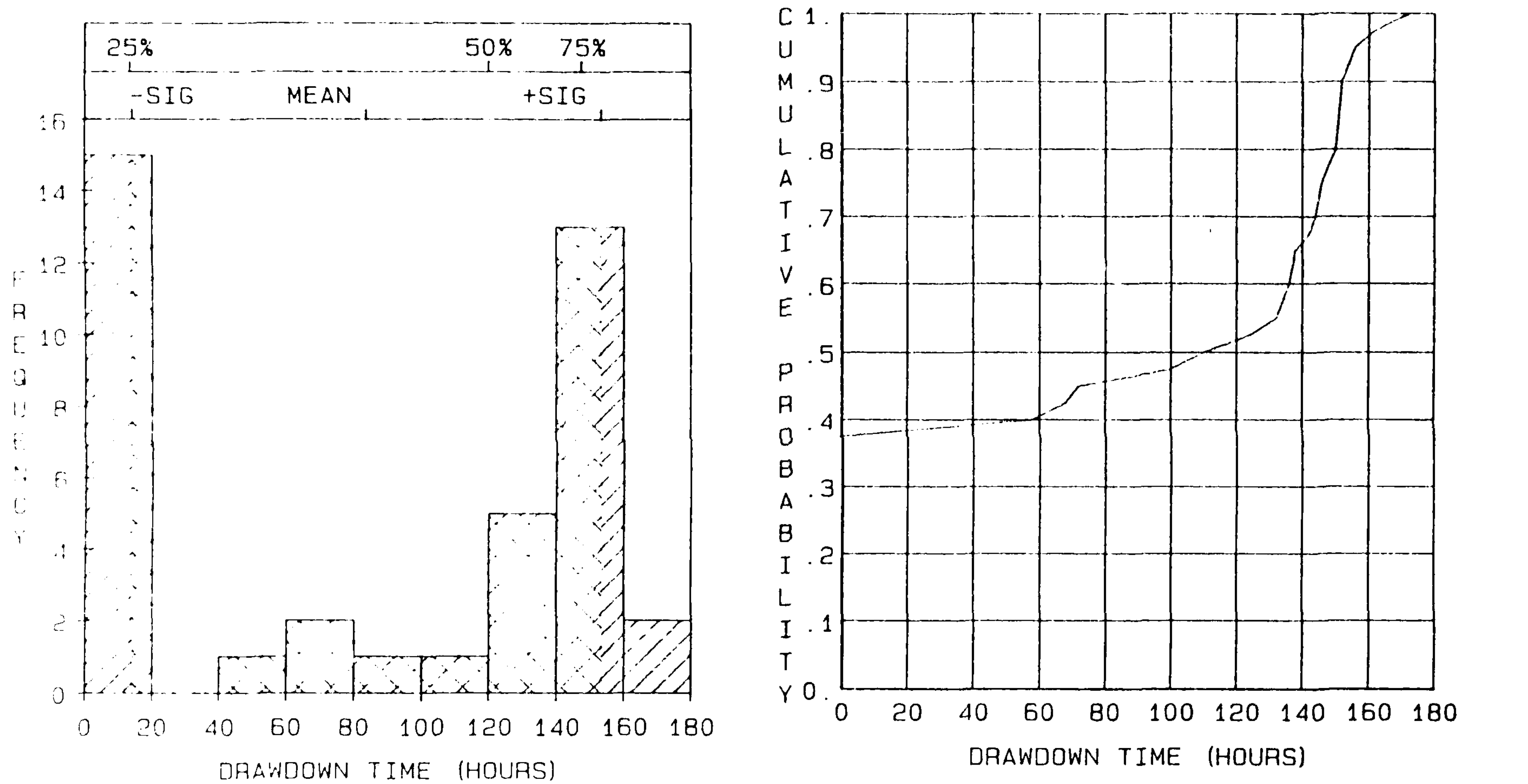


Figure 25. Battlefield assessment planning graphs for Reservoir Drawdown Strategy E (fast drawdown of Hwachon and Soyang Reservoirs during a simultaneous operation) depicting drawdown times for Soyang Dam, frequency histogram (left) and cumulative frequency distribution (right)

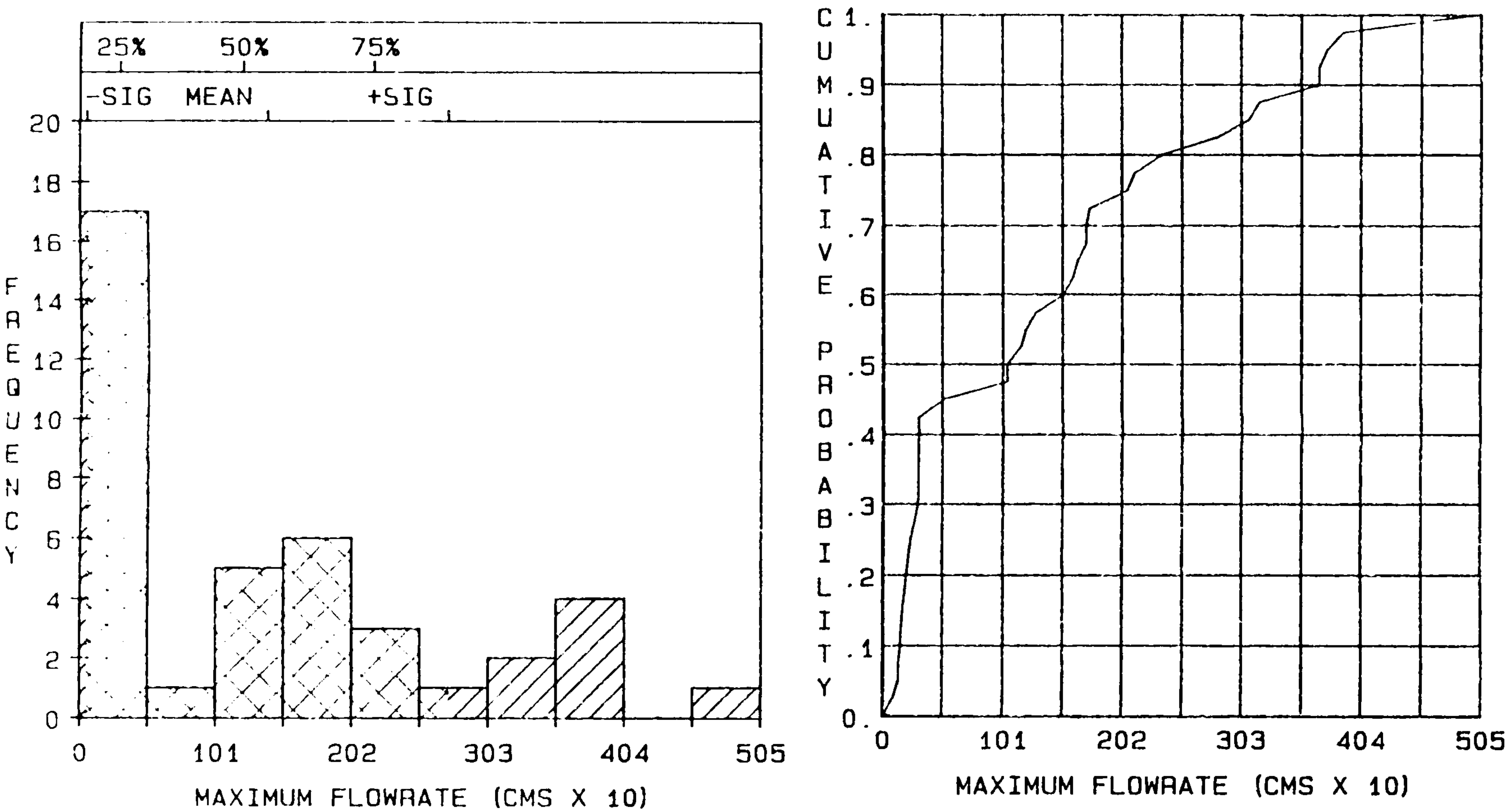


Figure 26. Battlefield assessment planning graphs for Reservoir Drawdown Strategy E (fast drawdown of Hwachon and Soyang Reservoirs during a simultaneous operation) depicting crossing site flow rates for Indogyo, frequency histogram (left) and cumulative frequency distribution (right)

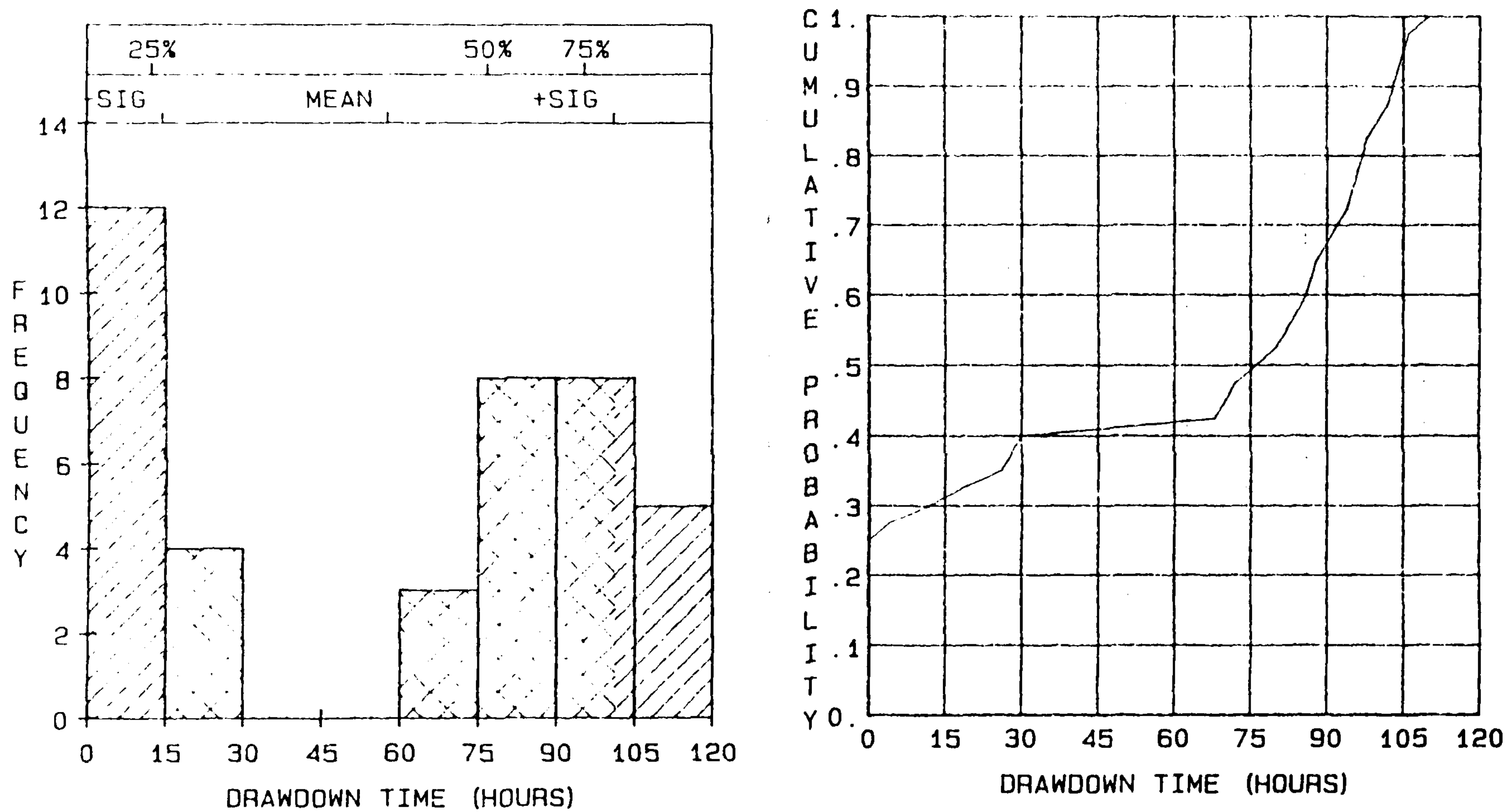


Figure 27. Battlefield assessment planning graphs for Reservoir Drawdown Strategy F (fast drawdown of Hwachon, Soyang, and Chunchon Reservoirs during a simultaneous operation) depicting drawdown times for Hwachon Dam, frequency histogram (left) and cumulative frequency distribution (right)

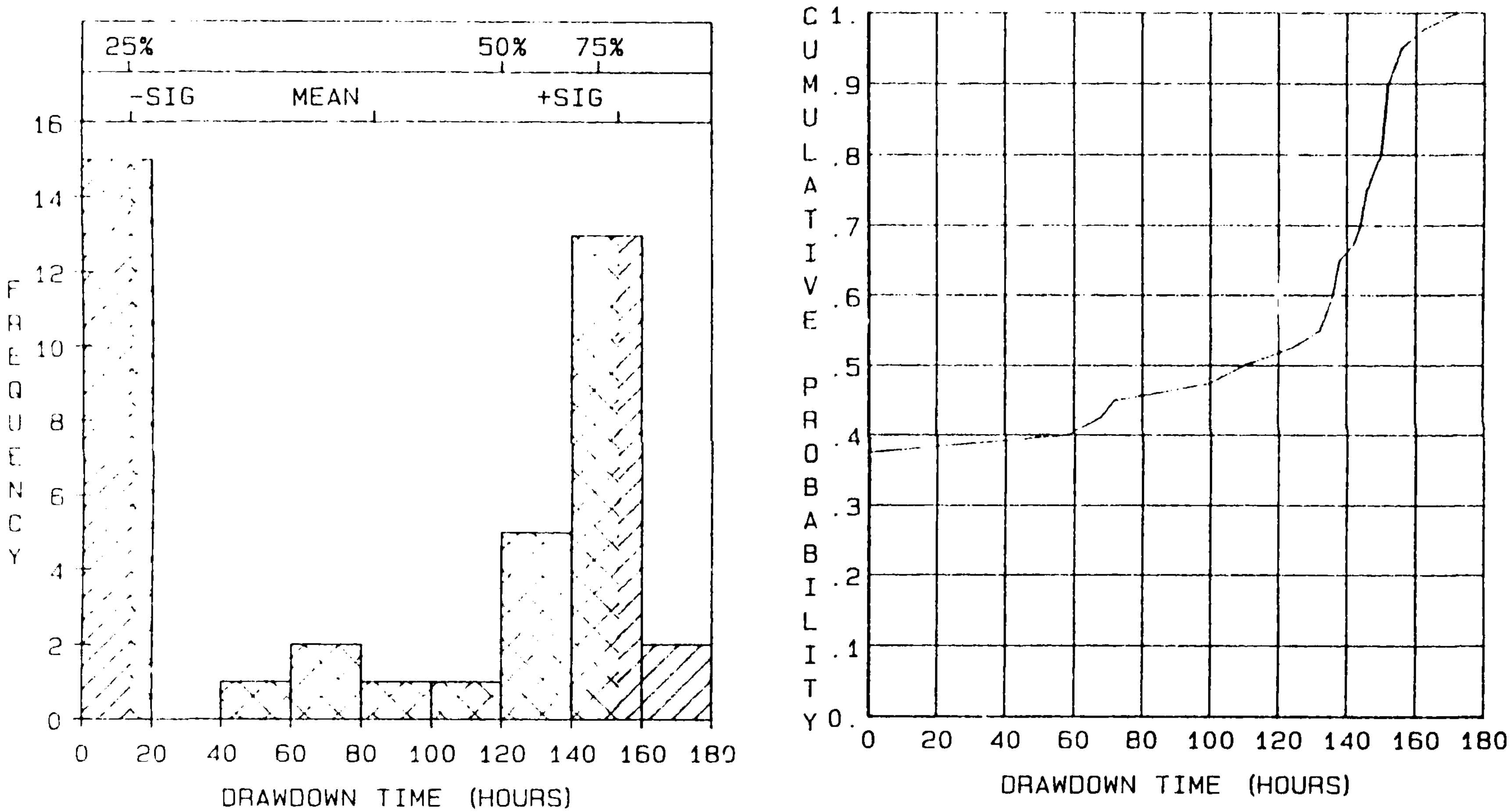


Figure 28. Battlefield assessment planning graphs for Reservoir Drawdown Strategy F (fast drawdown of Hwachon, Soyang, and Chunchon Reservoirs during a simultaneous operation) depicting drawdown times for Soyang Dam, frequency histogram (left) and cumulative frequency distribution (right)

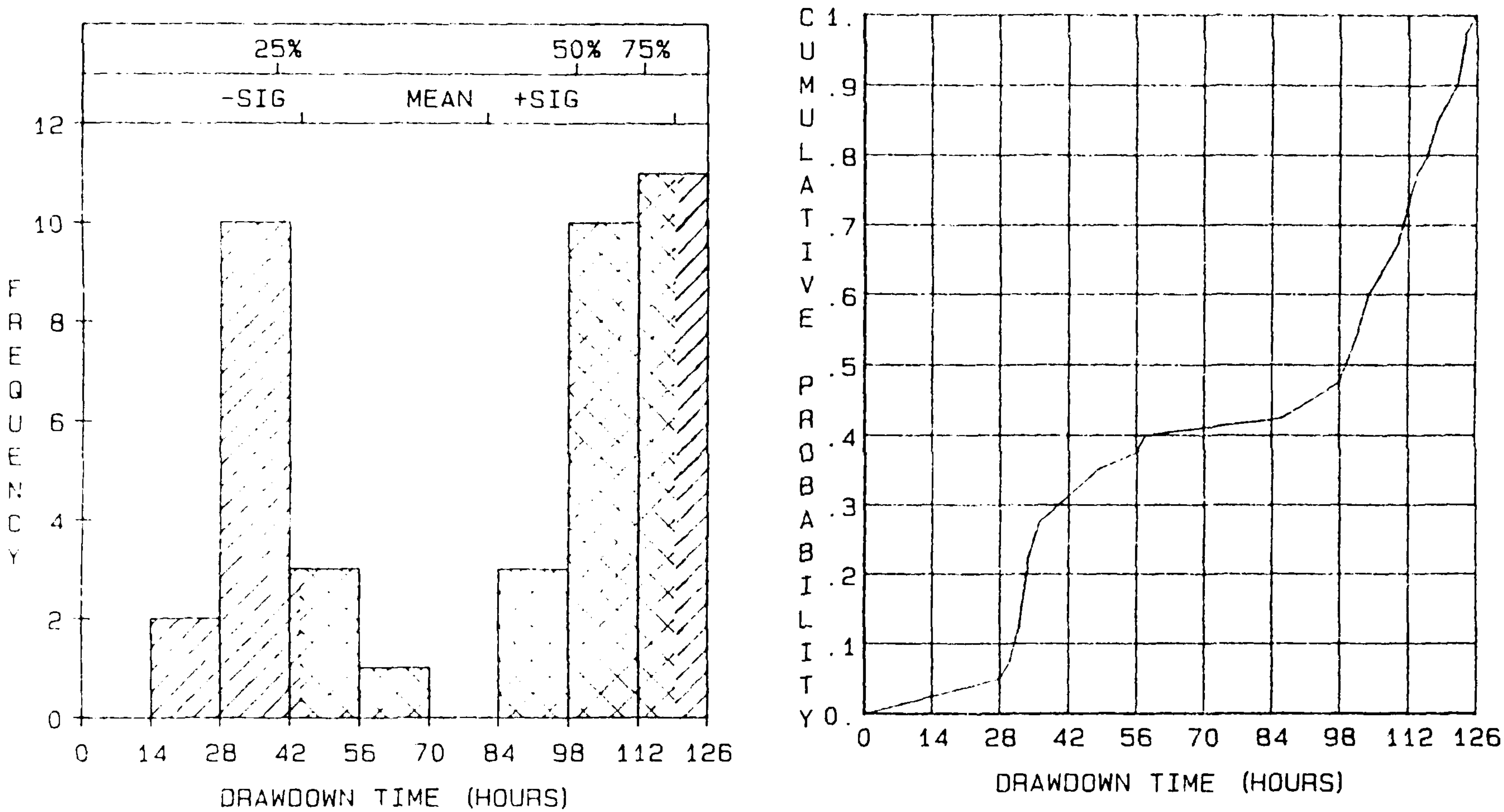


Figure 29. Battlefield assessment planning graphs for Reservoir Drawdown Strategy F (fast drawdown of Hwachon, Soyang, and Chunchon Reservoirs during a simultaneous operation) depicting drawdown times for Chunchon Dam, frequency histogram (left) and cumulative frequency distribution (right)

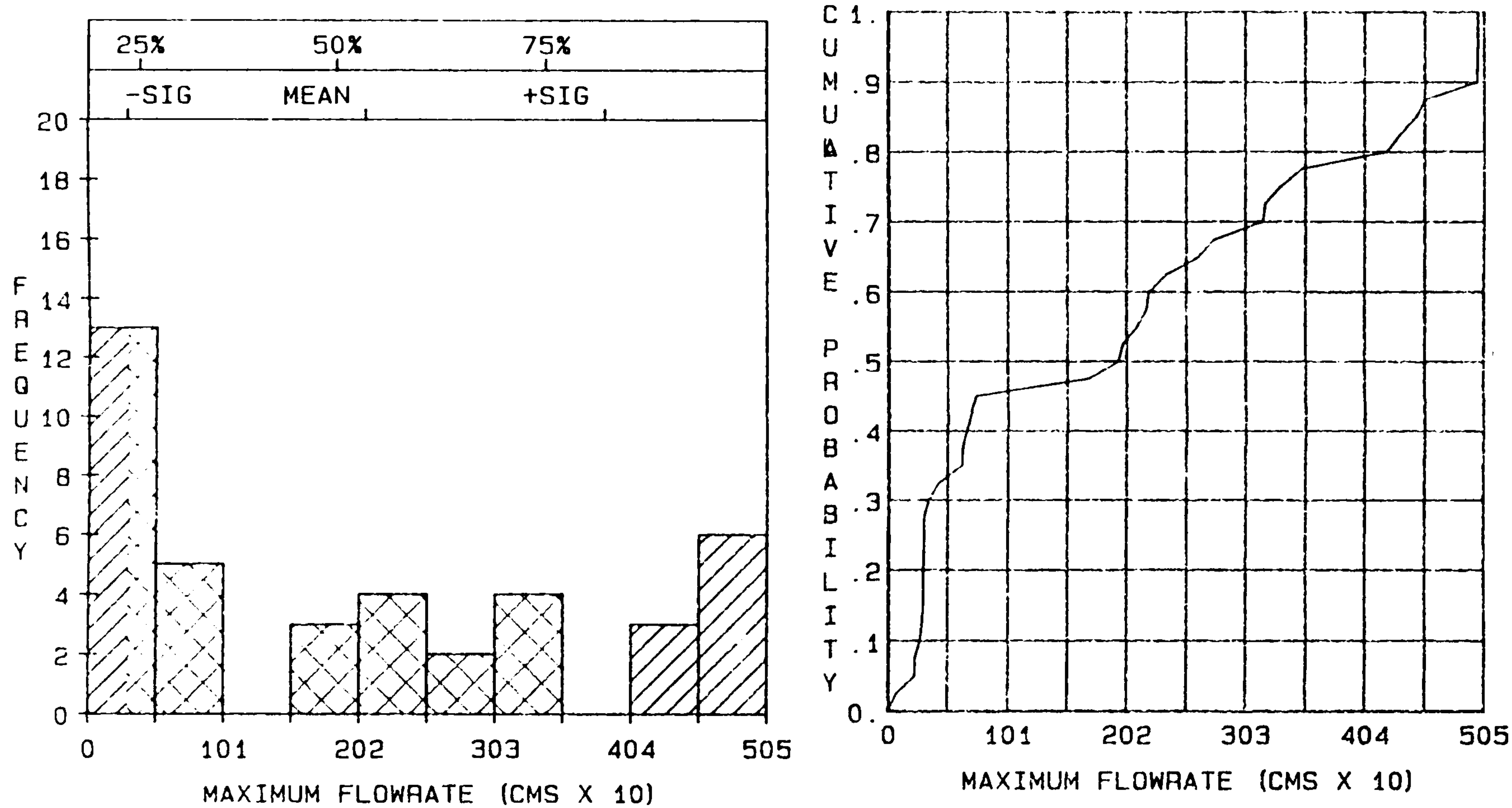


Figure 30. Battlefield assessment planning graphs for Reservoir Drawdown Strategy F (fast drawdown of Hwachon, Soyang and Chunchon Reservoirs during a simultaneous operation) depicting crossing site flow rates for Indogyo, frequency histogram (left) and cumulative frequency distribution (right)

CHAPTER V

ARTIFICIAL INTELLIGENCE APPLICATIONS FOR MILITARY HYDROLOGY

RESERVOIR DRAWDOWN EXPERT SYSTEM

The engineering analysis required to rapidly assess military courses of action involving reservoir system operations and determine the optimal procedure lends itself to the application of Artificial Intelligence (AI) techniques. The RAMBO concept is an ideal candidate for such an application because the procedures are highly complex, are quite time consuming, and if done using conventional techniques, require multiple input card changes and simulation runs to produce the desired drawdown results. Combining the expertise of hydrology and military tactics into a single stand-alone system is a problem well suited for the utilization of an expert system. This AI based program could incorporate computer modeling techniques, hydrologic experience, and the specialized skills of the military staff officers into a single system capable of supporting the fast-paced decision-making process envisioned on the modern AirLand Battlefield.

Current military policy requires that officers rotate between duty stations every three to four years. This constant turn-over cycle creates vulnerability windows at major Army command headquarters world wide as newly assigned officers begin the process of familiarizing themselves with theater specific contingency OPLANS, strategic objectives, and standard operating policies. An expert system could alleviate the problem of the "cold desk," a dilemma created when an officer rotates out of his current assignment before his replacement arrives, by retaining the problem-solving expertise essential to support sound military decisions during organizational turn-over cycles. The reservoir drawdown expert system could quickly address each tactical streamflow requirement and provide the military commander with the optimal drawdown strategy appropriate for the current battlefield situation.

Recognizing the military requirement for a reservoir drawdown expert system, the U.S. Army Engineer Waterways Experiment Station (WES) and the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) initiated a research project to develop a prototype Intelligent Decision Support Package (IDSP) for reservoir drawdown operations. The expert system framework for the IDSP was designed around the integrated procedures previously described as the RAMBO concept.

PROTOTYPE IDSP DEVELOPMENT

A prototype IDSP for reservoir drawdown operations (RAMBO-E) was completed in September 1987. The prototype contained an embedded expert system that could calculate reservoir drawdown times and crossing site flow rates for prespecified reservoir drawdown strategies (Strzepek, 1987). The initial IDSP, based on historical streamflow records and existing reservoir operation rule curves for the Han River Basin, Korea, was developed for long-range planning. The IDSP was capable of simulating any combination of drawdown scenarios involving the seven Han River reservoirs and evaluating critical flow rates at the Indogyo crossing site in Seoul, Korea (Figure 12). The system was designed around the concept of an interactive graphics framework (menu

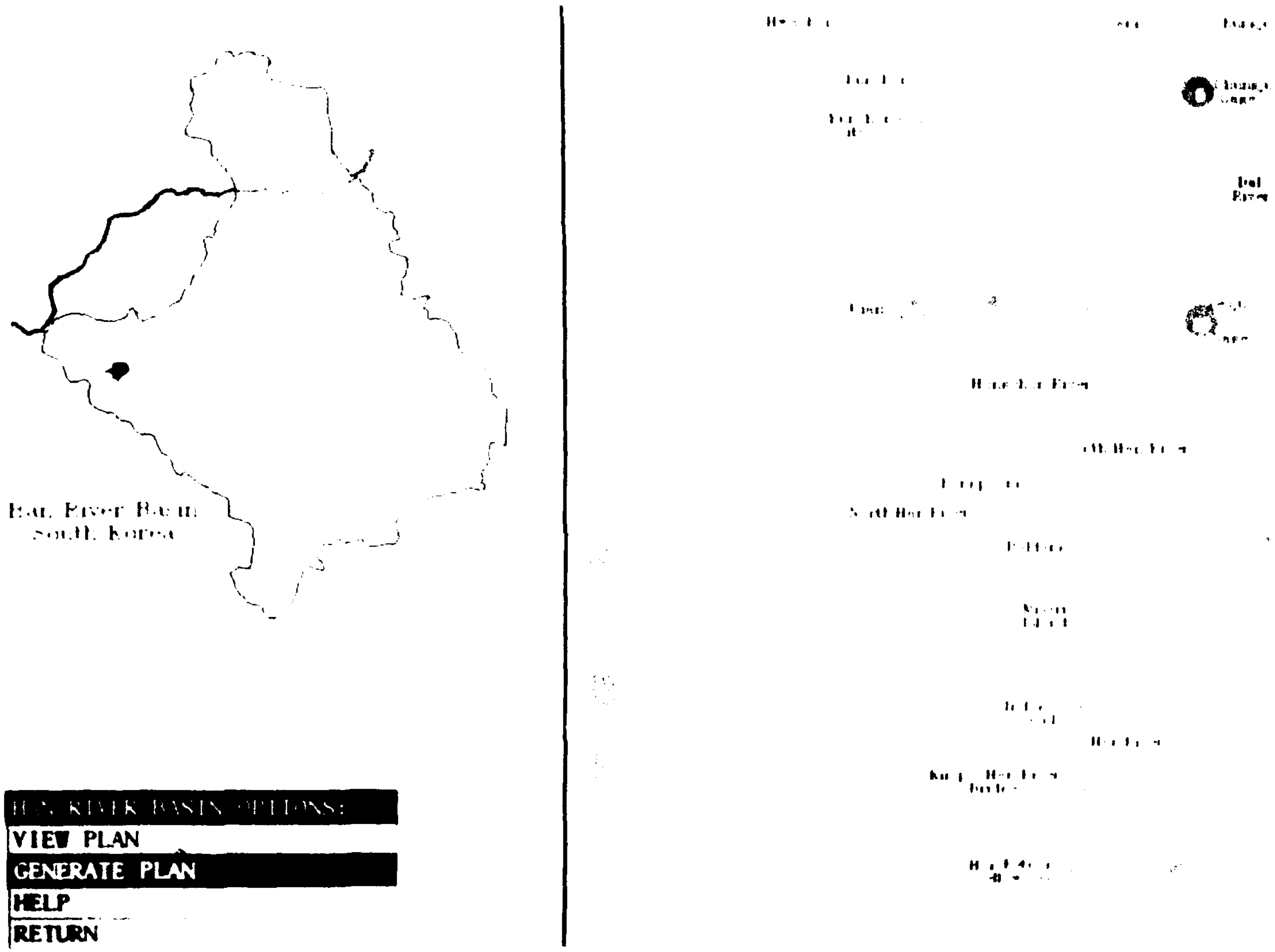


Figure 31. Computer generated map of the HRB (left) and schematic of the automated simulation system (right)

driven), enhanced data entry (mouse device), and rapid interpretation of simulation results using a color graphics monitor. Drawdown time frequency histograms and cumulative frequency distributions (Battlefield Assessment Planning Graphs) could be displayed for each reservoir with color shading indicating the statistical characteristics associated with each drawdown strategy (Figure 13). Four river crossing choices could be selected at the Indogyo site allowing model simulations to incorporate specific river crossing requirements in the Seoul area (Figure 14). IDSP output analysis could be used to supplement existing contingency planning guidance and update existing OPLANS.

The reservoir drawdown IDSP was demonstrated for U.S. Forces Korea (USFK) in October 1987. The IDSP demonstration, conducted in conjunction with a USFK readiness exercise, revealed that on-site Army estimation techniques provided inaccurate drawdown times. As a result of the demonstrations, USFK recommended that additional enhancements be included in RAMBO-E to further increase the effectiveness of the system.

NEXT GENERATION NOTIONAL CONCEPT FOR RAMBO-E

Future developments for the RAMBO-E intelligent decision support package should focus on combining dam-break numerical algorithms, reservoir drawdown modeling capabilities, trafficability analysis routines, rainfall-runoff prediction models, and tactical weather radar systems, into a comprehensive tactical decision tool. The engineering and military expertise required to rapidly assess the tactical and strategic implications associated with streamflow predictions (river

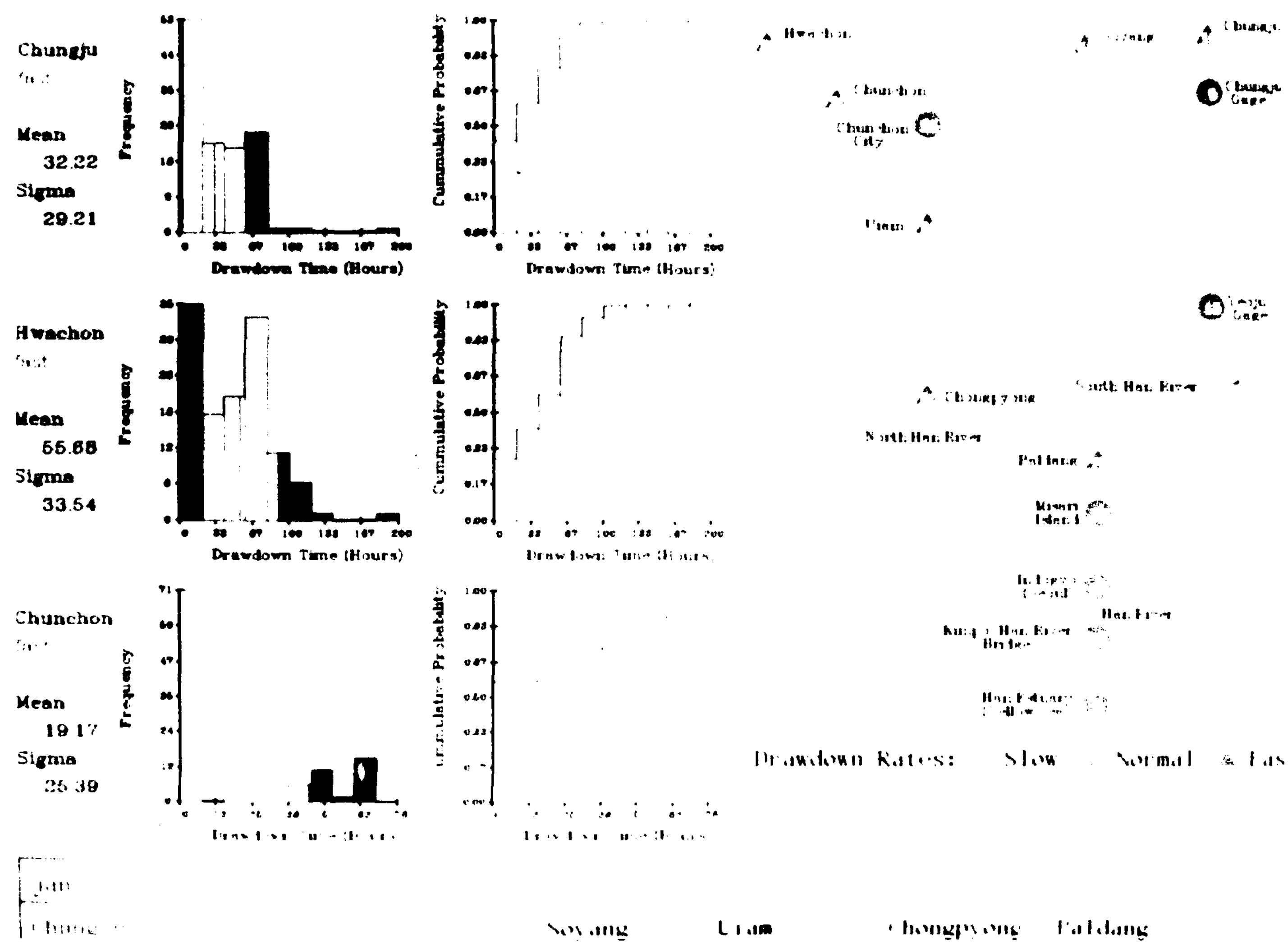


Figure 32. Drawdown time frequency histograms and cumulative frequency distributions for a simulated drawdown strategy are depicted for three reservoirs (left) with a schematic of the simulation system (right)

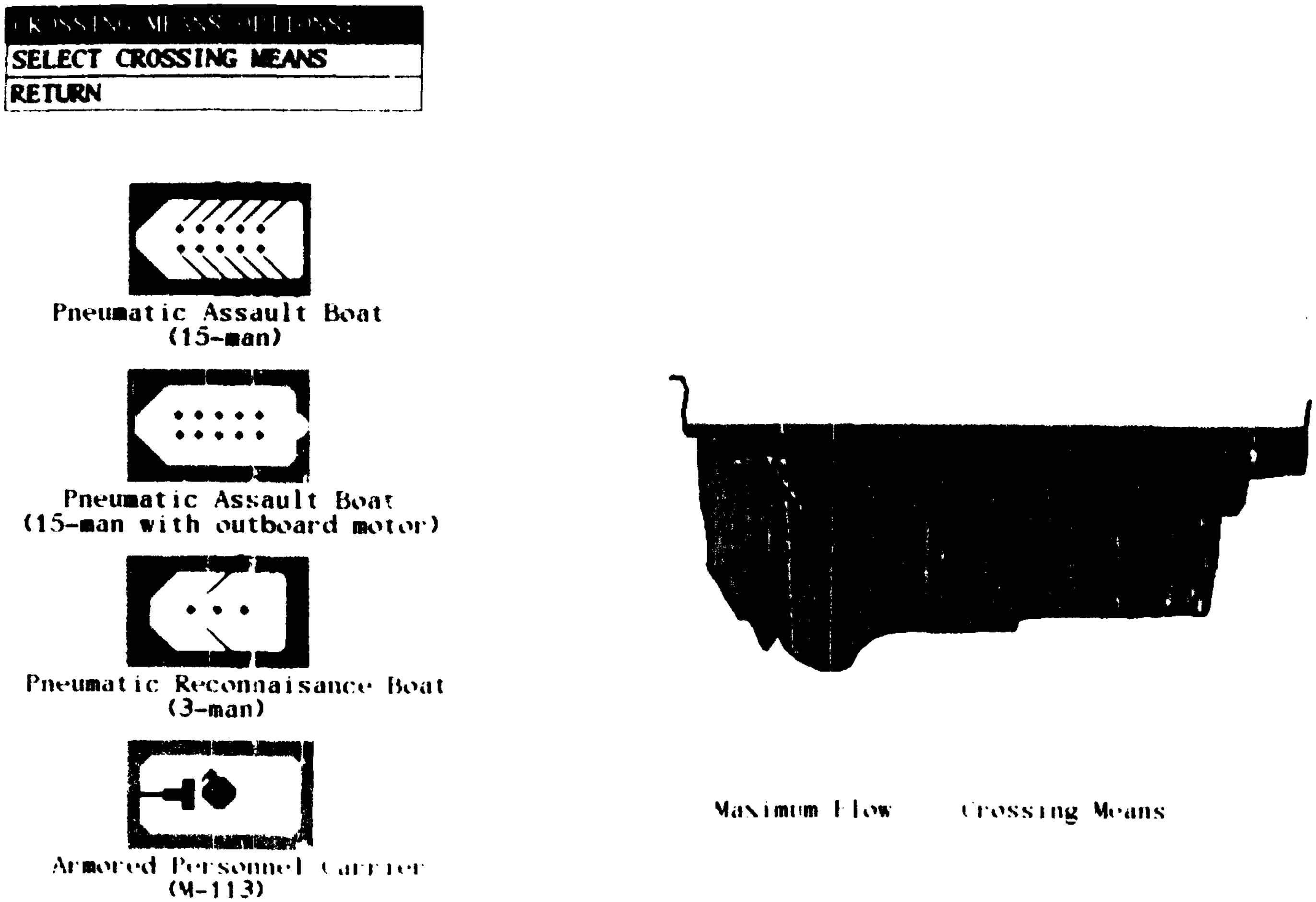


Figure 33. Graphic display of the crossing means option (left) with a cross-sectional view of the Indogyo crossing site, Seoul (right)

crossing sites), reservoir system operations (drawdown procedures), floods created by dam breaches (barrier obstacles), and the resultant soil moisture conditions (vehicle mobility), could be provided using an IDSP linked with an interactive graphics framework on a work station.

USFK currently recognizes the need for a reservoir drawdown model integrated with dam-break numerical algorithms; resultant information could be used to rapidly and effectively advise the commander on how to properly control the level of the Han River and its reservoirs to the advantage of U.S./South Korean forces during an armed conflict. The European and Middle Eastern military theaters have similar military hydrology applications that would support development of an IDSP. History indicates that dam breach flood waves can be used effectively during military operations. Although the potential use of such a system is clearly evident, no form of intelligent dam breach or reservoir drawdown system is fielded in any military theater.

Terrain analysts and engineer staff offices throughout the major army commands could effectively integrate an IDSP for military hydrology applications into their tactical and strategic planning processes. The benefits of the system are considerable; the military commander could be provided with both forecast or real-time hydrologic impacts within his entire area of operation based on computer analysis and embedded expertise, thus enabling him to make sound decisions rather than hasty military assessments.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Development and evaluation of the RAMBO analysis procedures represents the culmination of a three-year research effort. This new analysis procedure integrates state-of-the-art computer modeling techniques into OPLAN assessments, providing Army field commands with an improved reservoir drawdown planning capability. Military planners can realistically evaluate alternative reservoir drawdown strategies, forecast expected drawdown times, and estimate engineer river crossing equipment requirements based on numerical simulations and statistical inferences rather than educated guesswork. The procedures are highly complex and time consuming; however, the technique is site independent, facilitating its utilization in any military theater of operation.

The RAMBO concept was successfully applied to the Han River Basin in Korea, resulting in the development and evaluation of six pertinent reservoir drawdown strategies. Following the completion of this case study a joint research effort, initiated between WES and CADSWES, resulted in the development of a prototype reservoir drawdown expert system. This system was demonstrated for USFK in October 1987 utilizing the HRB as the test-bed scenario. Results of the demonstration revealed that existing Army estimation techniques provided inaccurate drawdown times validating the requirement for a tactical decision aid based on the RAMBO concept. In conjunction with USFK recommendations, current research efforts are geared toward the development of a basic expert system incorporating both the RAMBO concept and dam-break algorithms into a single rule-based system. Demonstration and fielding of this system is scheduled for October 1989.

RECOMMENDATIONS

As noted above, joint research efforts between WES and CADSWES have resulted in the development of a prototype expert system for evaluating reservoir drawdown contingency operations. Although this AI based system constitutes a marked improvement, model input conditions remain tied to extensive data collection requirements and engineering expertise. Future research efforts should focus on the development of a generic module based on expert system technology. The module should be capable of constructing a base line operating strategy utilizing existing data sources; it would be activated when data are not available or when the time-frame for analysis is limited. This expert system concept is extremely relevant because today's Army has a world-wide, no-notice deployment mission.

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APPENDIX A

RESERVOIR CHECKLISTS

Reservoir Checklist # 1 - Chungju

A. Name of Dam - Chungju Dam
B. Location of Dam (Grid Coordinates) - DR 105955
C. Name of the river basin - Han
D. River on which the dam is located - South Han
E. Drainage area above the dam - 6,648 square kilometers
F. Year in which the dam was completed - 1985
G. Purpose(s) of the dam

Flood Control	- X (primary)
Water Supply	- X (primary)
Electric Power	- X (primary)
Irrigation	- X (primary)
Navigation	-
Other	-

H. Type of dam and construction material

1. Type		2. Construction material	
Gravity	- X	Earth	-
Arch	-	Rockfill	-
Submerged Weir	-	Concrete	- X
Other	-	Other	-

I. Key dimensions of the dam

1. Height - 97.5 meters
2. Length - 464 meters
3. Volume - Unknown

'. Spillway data

1. Type

Overflow	- X
Chute	-
Side Channel	-
Siphon	-
None	-

2. Crest elevation - 123 meters

3. Clear length - 75 meters

4. Type of gates		5. Number	6. Dimensions (meters) (W x L)
Rolling	-		
Vertical Lift	-		
Tainter (Radial)	- X	5	15 x 21
Drum	-		
None	-		

7. Total discharge for the spillway gates at various water surface elevations

(Use the same elevations for item numbers J7, K7, L, M, Q, and R)

	Elevation (meters)	Discharge (cubic meters/second)
1.	86	0
2.	110	0
3.	120	0
4.	123	0
5.	130	3090
6.	135	6936
7.	141	12743
8.	145	17219
9.	147.5	20236

(Include the discharge rating curve if available)

K. Outlet Works Data

1. Type

Tunnel -
Conduit - X
Weir -
Other -
None -

2. Location

Through main dam - X
Through abutment -
Tunnel around end -
Other -

3. Size - 1.5 meters

4. Total Length - Unknown

5. Shape - Circular

6. Elevation of entrance centerline - 97 meters

7. Total discharge through the outlet works for various water surface elevations

	Elevation (meters)	Discharge (cubic meters/second)
1.	86	0
2.	110	41
3.	120	49
4.	123	51
5.	130	56
6.	135	59
7.	141	62
8.	145	64
9.	147.5	66

(Include the discharge rating curve if available)

L. Storage capacity and elevation data for the reservoir

	Elevation (meters)	Capacity (cubic meters x 10^3)
1.	86	70,000
2.	110	510,000
3.	120	935,000
4.	123	1,100,000
5.	130	1,505,000
6.	135	1,850,000
7.	141	2,330,000
8.	145	2,625.000
9.	147.5	2,900,000

(Include the capacity-elevation curve if available)

M. Area and elevation data for the reservoir

	Elevation (meters)	Area (square meters x 10^3)
1.	86	6200
2.	110	32,000
3.	120	48,200
4.	123	53,600
5.	130	55,000
6.	135	73,200
7.	141	83,200
8.	145	93,000
9.	147.5	99,000

(Include the area-elevation curve if available)

N. Key reservoir pool elevations and storage capacities

Pool Level	Elevation (meters)	Capacity (cubic meters x 10^3)
1. Top of Inactive	86	70,000
2. Top of Buffer	110	510,000
3. Top of Conservation	141	2,330,000
4. Top of Flood	145	2,625,000
5. Top of Dam	147.5	2,900,000

O. Tailwater elevations in stream at the foot of the dam

1. Maximum - 80.7 meters
2. Normal - 71.3 meters
3. Minimum - 64 meters

P. Monthly reservoir evaporation, precipitation, and net evaporation rates

Month	Evaporation (millimeters)	Precipitation (millimeters)	Net Evaporation (centimeters)
1. January	24.2	26	1.64
2. February	31.4	28.6	2.282
3. March	50.2	46.5	3.625
4. April	77.7	79.9	5.373
5. May	103.4	65.4	8.378
6. June	103.4	104.9	7.193
7. July	92.1	238.4	2.058
8. August	85.2	218.2	1.974
9. September	65.2	125.2	2.764
10. October	49.5	38.8	3.786
11. November	30.3	33.5	2.025
12. December	21.4	24.2	1.414

Q. Total discharge through the power penstocks at various water surface elevations

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	86	0
2.	110	0
3.	120	656
4.	123	684
5.	130	732
6.	135	768
7.	141	784
8.	145	784
9.	147.5	784

R. Total combined discharge capacity for all outlets, power penstocks and spillway gates at various water surface elevations

(Combine all discharge capacities listed in item numbers J7, K7, and Q)

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	86	0
2.	110	41
3.	120	705
4.	123	735
5.	130	3878
6.	135	7763
7.	141	13,589
8.	145	18,067
9.	147.5	21,086

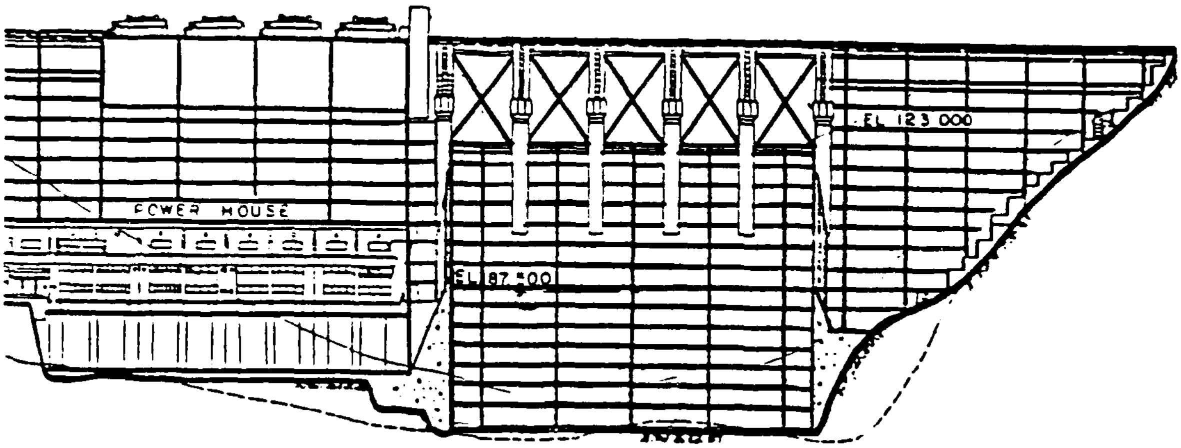

Figure 34. Frontal view of Chungju Dam and spillway gates

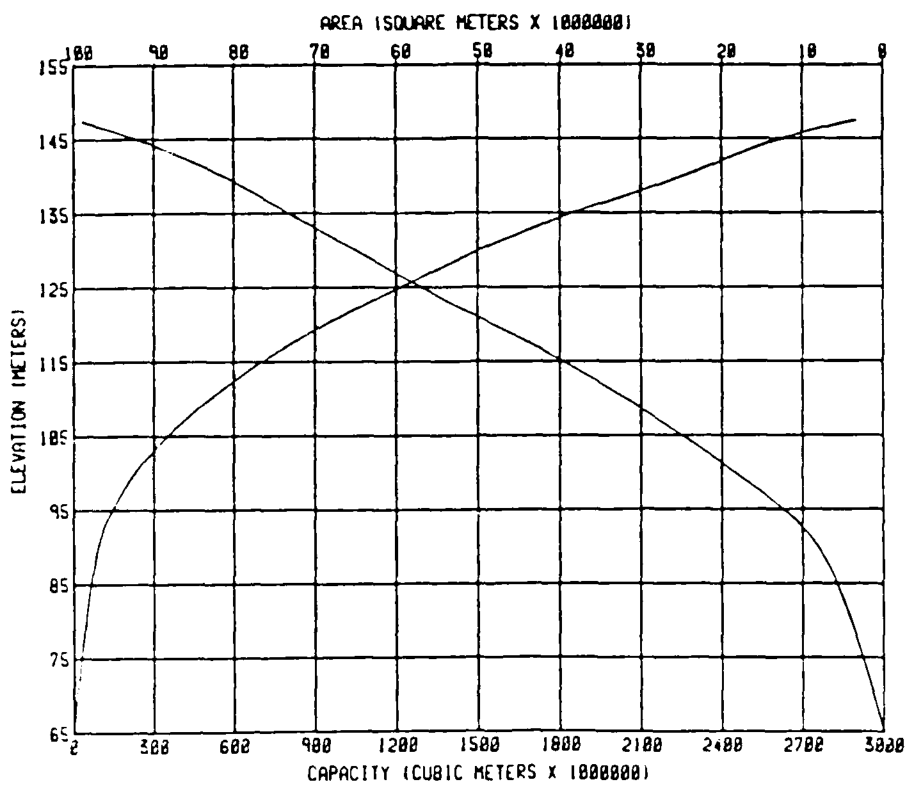

Figure 35. Area/capacity curves for Chungju Reservoir

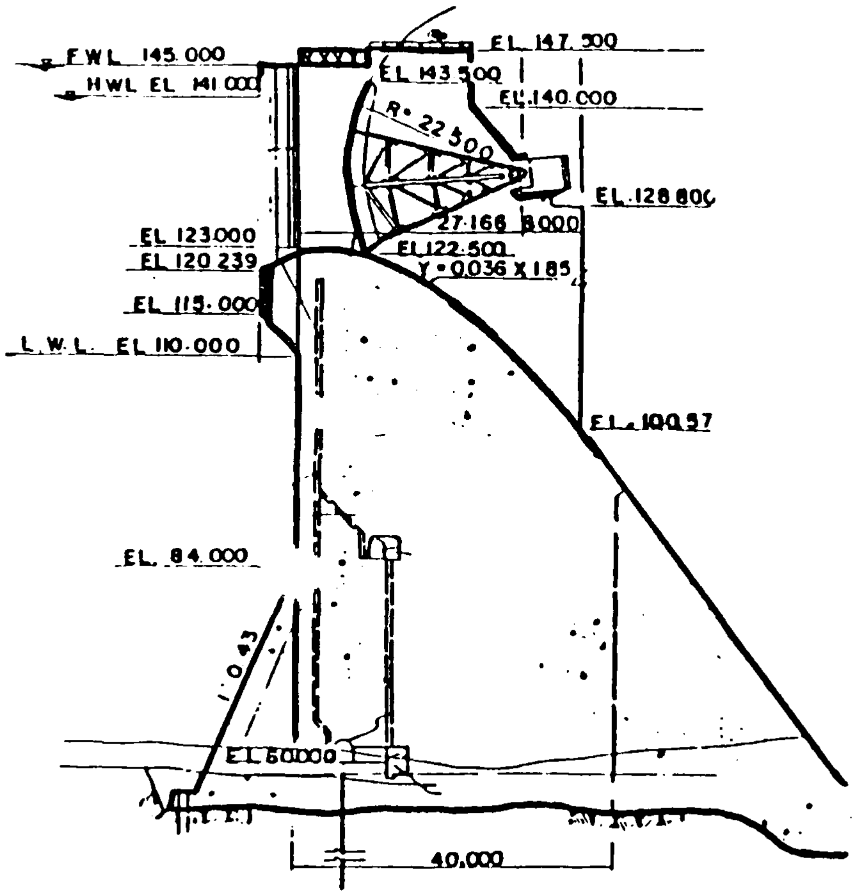

Figure 36. Cross-sectional view of Chungju Dam

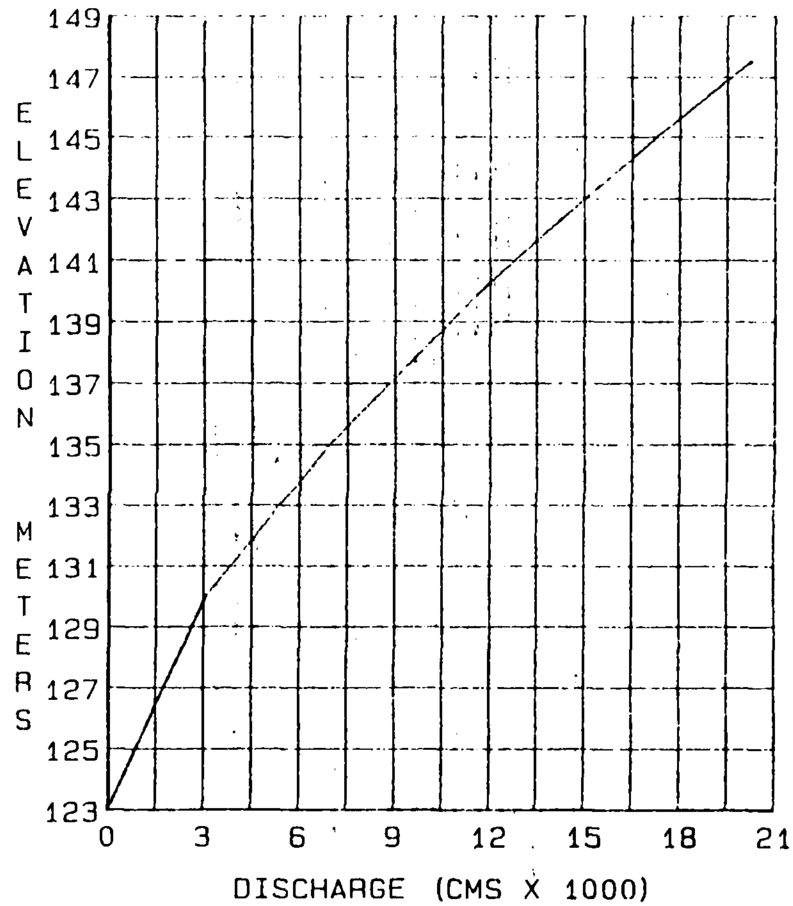

Figure 37. Spillway rating curve for Chungju Dam

Reservoir Checklist # 2 - Hwachon

A. Name of Dam - Hwachon
B. Location of Dam (Grid Coordinates) - CT 932188
C. Name of the river basin - Han
D. River on which the dam is located - North Han
E. Drainage area above the dam - 4,063 square kilometers
F. Year in which the dam was completed - 1944
G. Purpose(s) of the dam

Flood Control - X (secondary)
Water Supply - X (secondary)
Electric Power - X (primary)
Irrigation - X (secondary)
Navigation -
Other -

H. Type of dam and construction material

1. Type		2. Construction material	
Gravity	- X	Earth	-
Arch	-	Rockfill	-
Submerged Weir	-	Concrete	- X
Other	-	Other	-

I. Key dimensions of the dam

1. Height - 77.5 meters
2. Length - 435 meters
3. Volume - 817,000,000 cubic meters

J. Spillway data

1. Type

Overflow - X
Chute -
Side Channel -
Siphon -
None -

2. Crest elevation - 4 gates at 173 meters
12 gates at 175 meters

3. Clear length - 192 meters

4. Type of gates		5. Number	6. Dimensions (meters) (W x L)
Rolling	-		
Vertical Lift	- X	16	4 - 12 x 8 & 12 - 12 x 6
Tainter (Radial)	-		
Drum	-		

7. Total discharge for the spillway gates at various water surface elevations

(Use the same elevations for item numbers J7, K7, L, M, Q, and R)

	Elevation (meters)	Discharge (cubic meters/second)
1.	145.2	0
2.	156.8	0
3.	173	0
4.	175	241
5.	177	1,402
6.	179	3,290
7.	181	5,674
8.	183	7,499
9.	184.3	8,559

(Include the discharge rating curve if available)

K. Outlet Works Data - No outlet works

1. Type

   Tunnel -
   Conduit -
   Weir -
   Other -
   None -

2. Location

   Through main dam -
   Through abutment -
   Tunnel around end -
   Other -

3. Size -

4. Total Length -

5. Shape -

6. Elevation of entrance centerline -

7. Total discharge through the outlet works for various water surface elevations

	Elevation (meters)	Discharge (cubic meters/second)
1.		
2.		
3.		
4.		
5.	N/A	N/A
6.		
7.		
8.		
9.		

(Include the discharge rating curve if available)

L. Storage capacity and elevation data for the reservoir

	Elevation (meters)	Capacity (cubic meters x 10^3)
1.	145.2	126,000
2.	156.8	277,000
3.	173	650,000
4.	175	710,000
5.	177	771,000
6.	179	840,000
7.	181	905,000
8.	183	980,000
9.	184.5	1,025,000

(Include the capacity-elevation curve if available)

M. Area and elevation data for the reservoir

	Elevation (meters)	Area (square meters x 10^3)
1.	145.2	8,000
2.	156.8	15,200
3.	173	30,000
4.	175	32,500
5.	177	34,000
6.	179	36,200
7.	181	39,000
8.	183	41,500
9.	184.5	43,500

(Include the area-elevation curve if available)

N. Key reservoir pool elevations and storage capacities

Pool Level	Elevation (meters)	Capacity (cubic meters x 10^3)
1. Top of Inactive	145.2	126,000
2. Top of Buffer	156.8	277,000
3. Top of Conservation	181	905,000
4. Top of Flood	183	980,000
5. Top of Dam	184.5	1,025,000

O. Tailwater elevations in stream at the foot of the dam

1. Maximum -
2. Normal - 103 meters (Fixed head loss = 3.5 meters)
3. Minimum -

P. Monthly reservoir evaporation, precipitation, and net evaporation rates

Month	Evaporation (millimeters)	Precipitation (millimeters)	Net Evaporation (centimeters)
1. January	27	29.2	1.824
2. February	31	25.4	2.338
3. March	47.3	40.7	3.509
4. April	78.6	90.2	5.154
5. May	103.2	87.4	7.698
6. June	103.2	130.7	6.399
7. July	86.8	367.5	- 2.345
8. August	78.6	321.9	- 1.797
9. September	64.5	142.5	2.175
10. October	50.8	38.7	3.919
11. November	31.7	21.3	2.531
12. December	27	19.7	2.109

Q. Total discharge through the power penstocks at various water surface elevations

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	145.2	0
2.	156.8	145
3.	173	165
4.	175	167
5.	177	169
6.	179	171
7.	181	173
8.	183	176
9.	184.3	179

R. Total combined discharge capacity for all outlets, power penstocks and spillway gates at various water surface elevations

(Combine all discharge capacities listed in item numbers J7, K7, and Q)

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	145.2	0
2.	156.8	145
3.	173	165
4.	175	408
5.	177	1,571
6.	179	3,461
7.	181	5,847
8.	183	7,675
9.	184.3	8,738

Figure 38. Frontal view of Hwachon Dam

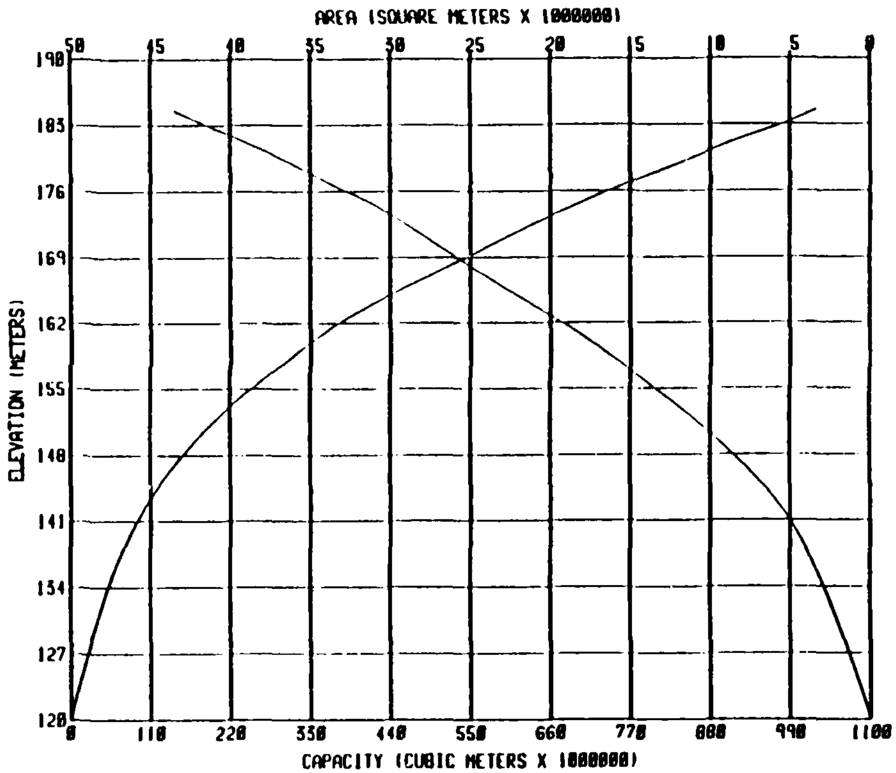

Figure 39. Area/capacity curves for Hwachon Reservoir

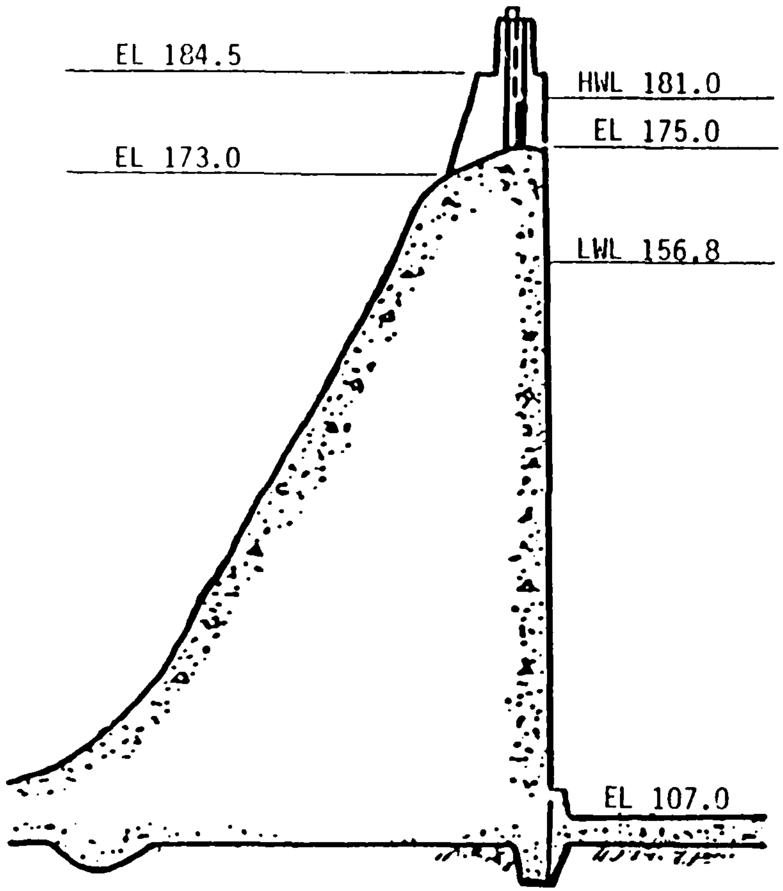

Figure 40. Cross-sectional view of Hwachon Dam

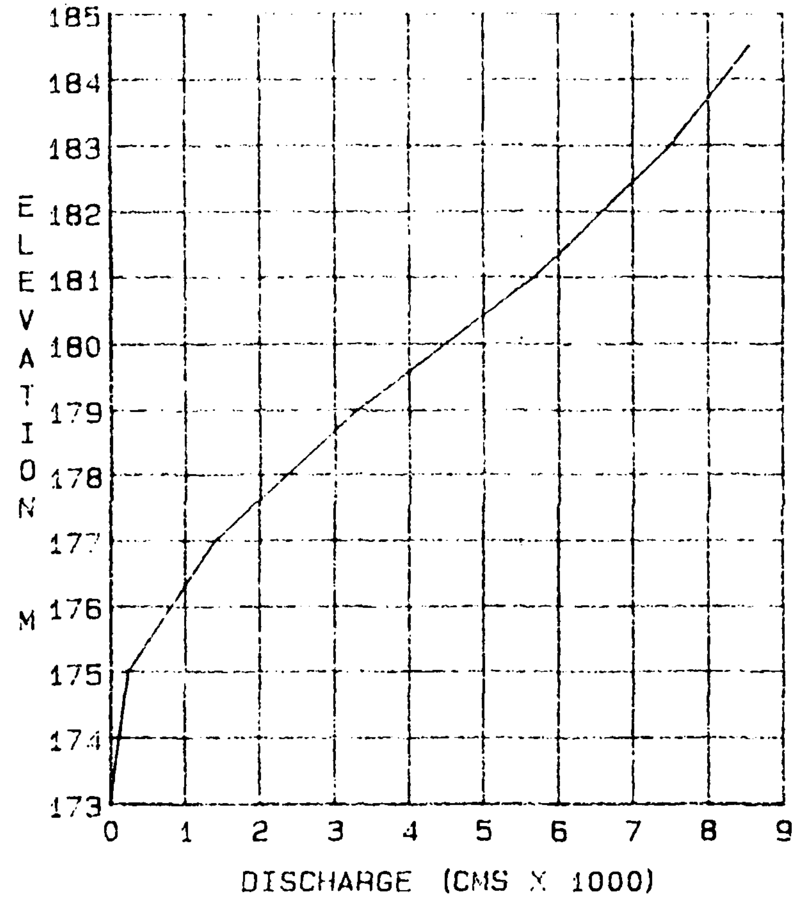

Figure 41. Spillway rating curve for Hwachon Dam

Reservoir Checklist # 3 - Chunchon

A. Name of Dam - Chunchon
B. Location of Dam (Grid Coordinates) - CT 832025
C. Name of the river basin - Han
D. River on which the dam is located - North Han
E. Drainage area above the dam - 4,841 square kilometers
F. Year in which the dam was completed - 1965
G. Purpose(s) of the dam

Flood Control	-
Water Supply	- X (secondary)
Electric Power	- X (primary)
Irrigation	- X (secondary)
Navigation	-
Other	-

H. Type of dam and construction material

1. Type		2. Construction material	
Gravity	- X	Earth	-
Arch	-	Rockfill	-
Submerged Weir	-	Concrete	- X
Other	-	Other	-

I. Key dimensions of the dam

1. Height - 40 meters
2. Length - 453 meters
3. Volume - 251,000,000 cubic meters

J. Spillway data

1. Type

Overflow	- X
Chute	-
Side Channel	-
Siphon	-
None	-

2. Crest elevation - 90.8 meters

3. Clear length - 144 meters

4. Type of gates		5. Number	6. Dimensions (meters) (W x L)
Rolling	-		
Vertical Lift	-		
Tainter (Radial)	- X	12	12 x 12.9
Drum	-		
None	-		

7. Total discharge for the spillway gates at various water surface elevations

(Use the same elevations for item numbers J7, K7, L, M, Q, and R)

	Elevation (meters)	Discharge (cubic meters/second)
1.	90.8	0
2.	96	3,060
3.	98	5,100
4.	100	7,800
5.	102	10,944
6.	103	12,600
7.	105	15,900
8.	107	19,200

(Include the discharge rating curve if available)

K. Outlet Works Data - No outlet works

1. Type

   Tunnel -
   Conduit -
   Weir -
   Other -
   None -

2. Location

   Through main dam -
   Through abutment -
   Tunnel around end -
   Other -

3. Size -

4. Total Length -

5. Shape -

6. Elevation of entrance centerline -

7. Total discharge through the outlet works for various water surface elevations

	Elevation (meters)	Discharge (cubic meters/second)
1.		
2.		
3.		
4.		
5.	N/A	N/A
6.		
7.		
8.		

(Include the discharge rating curve if available)

L. Storage capacity and elevation data for the reservoir

	Elevation (meters)	Capacity (cubic meters x 10^3)
1.	90.8	37,383
2.	96	85,981
3.	98	89,821
4.	100	111,062
5.	102	135,902
6.	103	150,000
7.	105	220,000
8.	107	240,000

(Include the capacity-elevation curve if available)

M. Area and elevation data for the reservoir

	Elevation (meters)	Area (square meters x 10^3)
1.	90.8	5,278
2.	96	7,830
3.	98	9,692
4.	100	11,549
5.	102	13,290
6.	103	14,150
7.	105	15,700
8.	107	17,449

(Include the area-elevation curve if available)

N. Key reservoir pool elevations and storage capacities

Pool Level	Elevation (meters)	Capacity (cubic meters x 10^3)
1. Top of Inactive	90.8	37,383
2. Top of Buffer	98	89,821
3. Top of Conservation	103	150,000
4. Top of Flood	104.9	218,000
5. Top of Dam	107	240,000

O. Tailwater elevations in stream at the foot of the dam

1. Maximum - 83.5 meters
2. Normal - 74 meters (Fixed head loss = .2 meters)
3. Minimum - 72 meters

P. Monthly reservoir evaporation, precipitation, and net evaporation rates

	Month	Evaporation (millimeters)	Precipitation (millimeters)	Net Evaporation (centimeters)
1.	January	24.2	26	1.64
2.	February	31.4	28.6	2.282
3.	March	50.2	46.5	3.625
4.	April	77.7	79.9	5.373
5.	May	103.4	65.4	8.378
6.	June	103.4	104.9	7.193
7.	July	92.1	238.4	2.058
8.	August	85.2	218.2	1.964
9.	September	65.2	125.2	2.764
10.	October	49.5	38.8	3.786
11.	November	30.3	33.5	2.025
12.	December	21.4	24.2	1.414

Q. Total discharge through the power penstocks at various water surface elevations

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	90.8	0
2.	96	0
3.	98	174
4.	100	186
5.	102	210
6.	103	228
7.	105	228
8.	107	228

R. Total combined discharge capacity for all outlets, power penstocks and spillway gates at various water surface elevations

(Combine all discharge capacities listed in item numbers J7, K7, and Q)

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	90.8	0
2.	96	3,060
3.	98	5,274
4.	100	7,986
5.	102	11,154
6.	103	12,828
7.	105	16,128
8	107	19,428

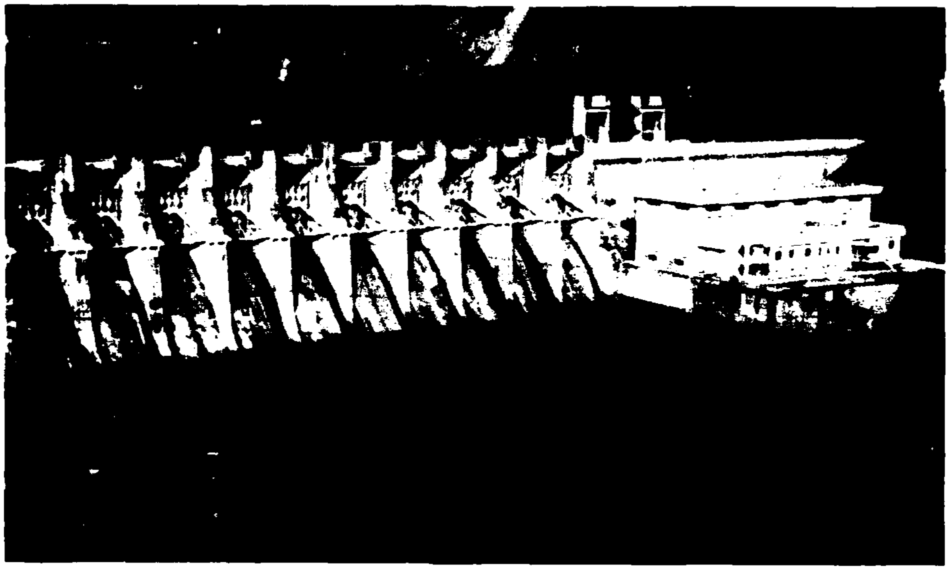

Figure 42. Frontal view of Chunchon Dam and spillway gates

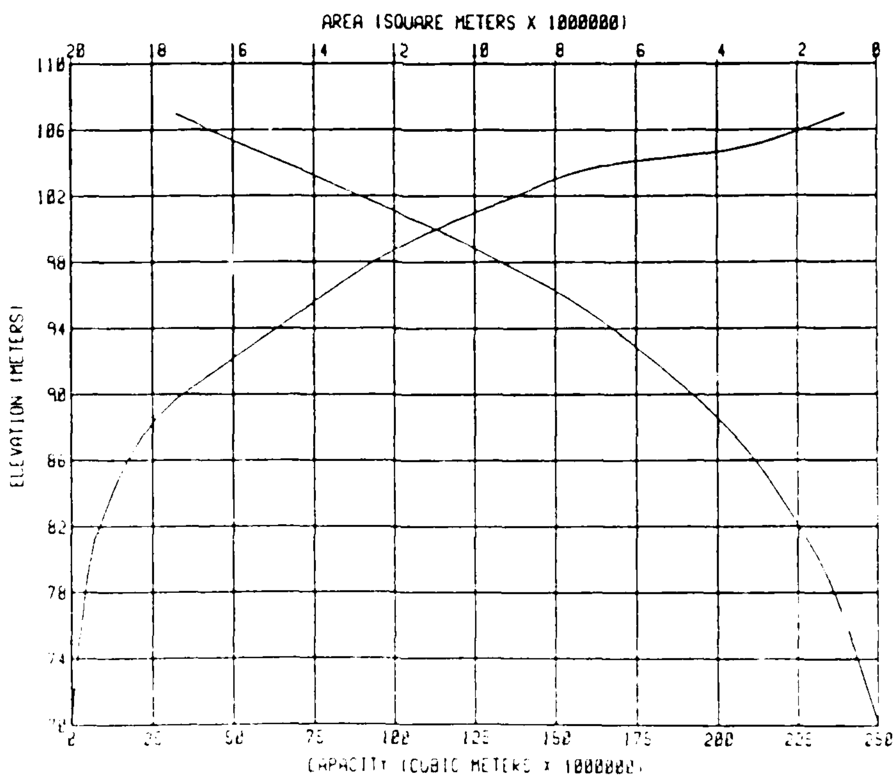

Figure 43. Area/capacity curves for Chunchon Reservoir

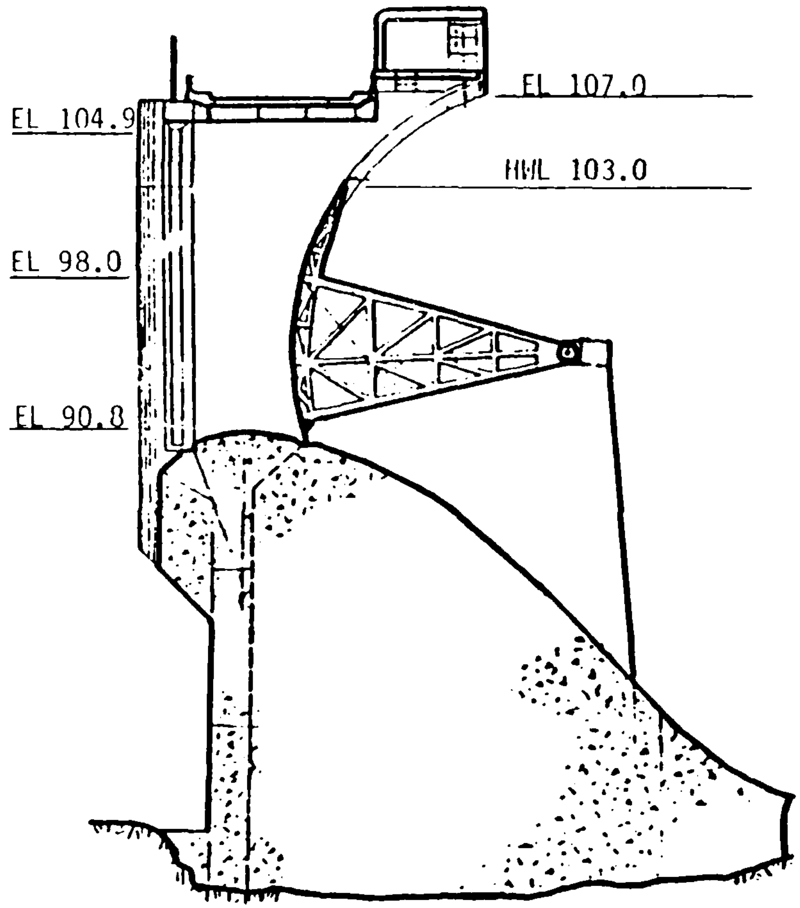

Figure 44. Cross-sectional view of Chunchon Dam

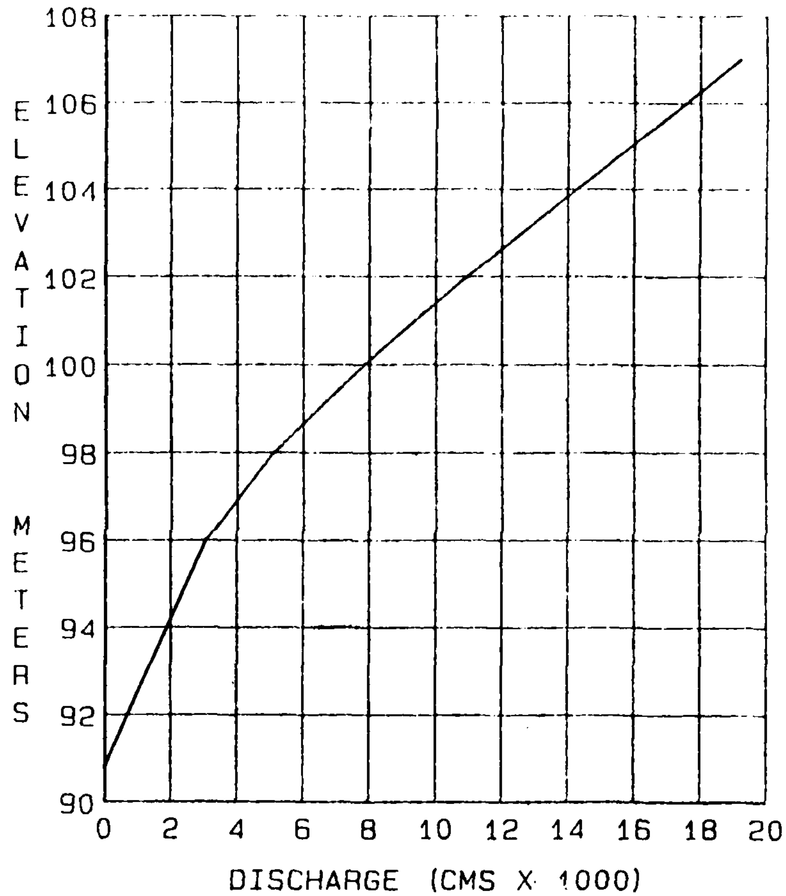

Figure 45. Spillway rating curve for Chunchon Dam

Reservoir Checklist # 4 - Soyang

A. Name of Dam - Soyang
B. Location of Dam (Grid Coordinates) - CS 960997
C. Name of the river basin - Han
D. River on which the dam is located - Soyang
E. Drainage area above the dam - 2,703 square kilometers
F. Year in which the dam was completed - 1972
G. Purpose(s) of the dam

Flood Control	- X (primary)
Water Supply	- X (primary)
Electric Power	- X (primary)
Irrigation	- X (primary)
Navigation	-
Other	-

H. Type of dam and construction material

1. Type		2. Construction material	
Gravity	- X	Earth	-
Arch	-	Rockfill	-
Submerged Weir	-	Concrete	- X
Other	-	Other	-

I. Key dimensions of the dam

1. Height - 123 meters
2. Length - 530 meters
3. Volume - 9,600,000,000 cubic meters

J. Spillway data

1. Type

Overflow	- X
Chute	-
Side Channel	-
Siphon	-
None	-

2. Crest elevation - 185.5 meters

3. Clear length - 65 meters

4. Type of gates		5. Number	6. Dimensions (meters) (W x L)
Rolling	-		
Vertical Lift	-		
Tainter (Radial)	- X	5	13 x 13
Drum	-		
None	-		

7. Total discharge for the spillway gates at various water surface elevations

(Use the same elevations for item numbers J7, K7, L, M, Q, and R)

	Elevation (meters)	Discharge (cubic meters/second)
1.	120	0
2.	150	0
3.	160	0
4.	185.5	0
5.	188	419
6.	190	1,088
7.	193.5	2,704
8.	198	5,640
9.	203	9,160

(Include the discharge rating curve if available)

K. Outlet Works Data

1. Type

Tunnel -
Conduit - X
Weir -
Other -
None -

2. Location

Through main dam - X
Through abutment -
Tunnel around end -
Other -

3. Size - 1.6 meters

4. Total Length - Unknown

5. Shape - Hollow Jet

6. Elevation of entrance centerline - Unknown

7. Total discharge through the outlet works for various water surface elevations

	Elevation (meters)	Discharge (cubic meters/second)
1.	120	41.5
2.	150	57
3.	160	61
4.	185.5	71
5.	188	72
6.	190	73
7.	193.5	74
8.	198	75
9.	203	77

(Include the discharge rating curve if available)

L. Storage capacity and elevation data for the reservoir

	Elevation (meters)	Capacity (cubic meters x 10^3)
1.	120	165,000
2.	150	650,000
3.	160	925,000
4.	185.5	1,990,000
5.	188	2,150,000
6.	190	2,260,000
7.	193.5	2,490,000
8.	198	2,900,000
9.	203	3,200,000

(Include the capacity-elevation curve if available)

M. Area and elevation data for the reservoir

	Elevation (meters)	Area (square meters x 10^3)
1.	120	9,300
2.	150	23,000
3.	160	28,000
4.	185.5	60,000
5.	188	63,000
6.	190	65,300
7.	193.5	69,500
8.	198	75,000
9.	203	80,200

(Include the area-elevation curve if available)

N. Key reservoir pool elevations and storage capacities

Pool Level	Elevation (meters)	Capacity (cubic meters x 10^3)
1. Top of Inactive	120	165,000
2. Top of Buffer	150	650,000
3. Top of Conservation	193.5	2,490,000
4. Top of Flood	198	2,900,000
5. Top of Dam	203	3,200,000

O. Tailwater elevations in stream at the foot of the dam

1. Maximum - 88 meters
2. Normal - 80.7 meters (Fixed head loss = 3.7 meters)
3. Minimum -

P. Monthly reservoir evaporation, precipitation, and net evaporation rates

	Month	Evaporation (millimeters)	Precipitation (millimeters)	Net Evaporation (centimeters)
1.	January	25.6	27.6	1.732
2.	February	28.9	30.6	1.972
3.	March	47.1	47.2	3.294
4.	April	78.6	90.4	5.148
5.	May	103.9	76.6	8.092
6.	June	103.6	133	6.37
7.	July	86.6	383.9	- 2.857
8.	August	81.9	311.2	- 1.146
9.	September	66.1	143.6	2.302
10.	October	50.7	36.8	3.966
11.	November	30.7	27.8	2.236
12.	December	24.4	20.4	1.828

Q. Total discharge through the power penstocks at various water surface elevations

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	120	0
2.	150	214
3.	160	227
4.	185.5	218
5.	188	211
6.	190	206
7.	193.5	202
8.	198	200
9.	203	200

R. Total combined discharge capacity for all outlets, power penstocks and spillway gates at various water surface elevations

(Combine all discharge capacities listed in item numbers J7, K7, and Q)

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	120	41.5
2.	150	271
3.	160	288
4.	185.5	289
5.	188	702
6.	190	1,367
7.	193.5	2,980
8	198	5,915
9.	203	9,437

Figure 46. Frontal view of Soyang Dam and emergency spillway

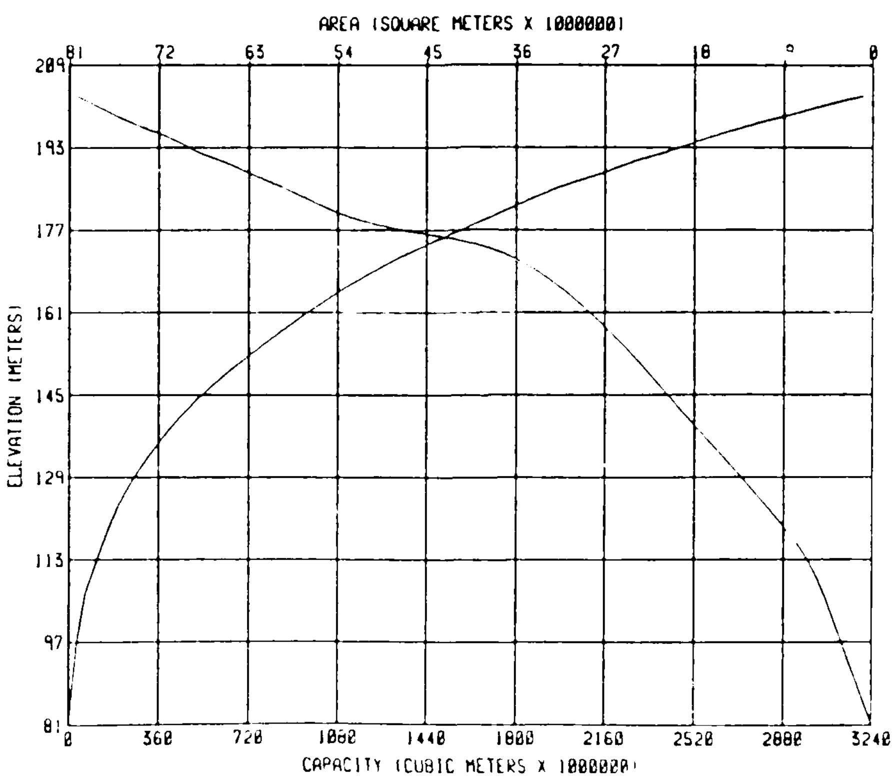

Figure 47. Area/capacity curves for Soyang Reservoir

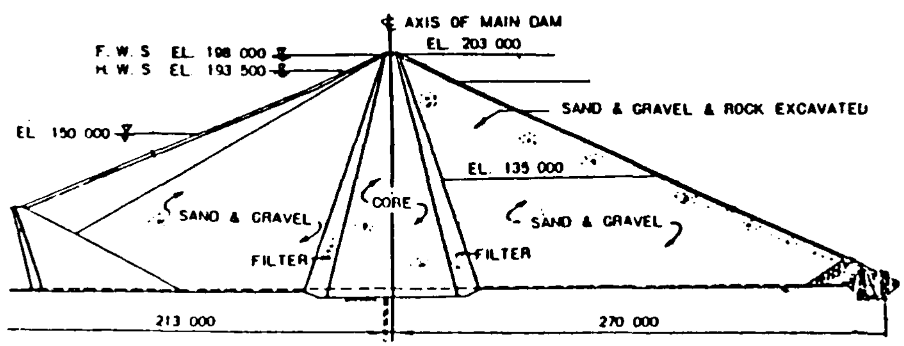

Figure 48. Cross-sectional view of Soyang Dam

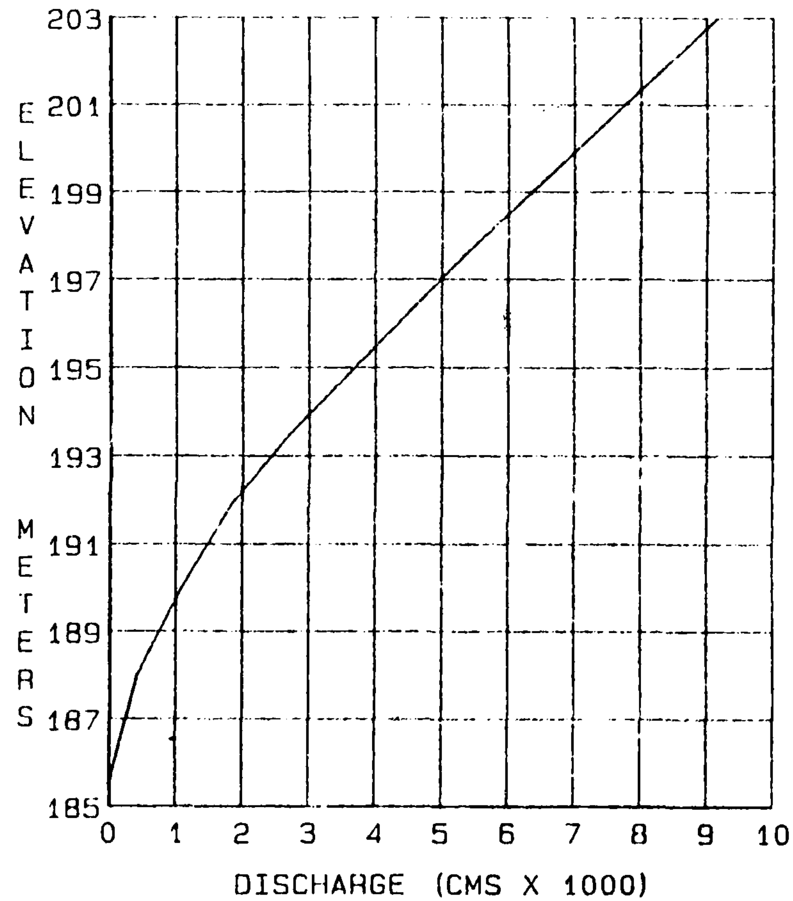

Figure 49. Spillway rating curve for Soyang Dam

Reservoir Checklist # 5 - Uiam

A. Name of Dam - Uiam
B. Location of Dam (Grid Coordinates) - CS 836878
C. Name of the river basin - Han
D. River on which the dam is located - North Han
E. Drainage area above the dam - 7,829 square kilometers
F. Year in which the dam was completed - 1967
G. Purpose(s) of the dam

Flood Control -
Water Supply - X (secondary)
Electric Power - X (primary)
Irrigation -
Navigation -
Other -

H. Type of dam and construction material

1. Type		2. Construction material	
Gravity	- X	Earth	-
Arch	-	Rockfill	-
Submerged Weir	-	Concrete	- X
Other	-	Other	-

I. Key dimensions of the dam

1. Height - 17.5 meters
2. Length - 273 meters
3. Volume - 36,000,000 cubic meters

J. Spillway data:

1. Type

Overflow - X
Chute -
Side Channel -
Siphon -
None -

2. Crest elevation - 57 meters

3. Clear length - 182 meters

4. Type of gates		5. Number	6. Dimensions (meters) (W x L)
Rolling	-		
Vertical Lift	- X	14	13 x 14.5
Tainter (Radial)	-		
Drum	-		
None	-		

7. Total discharge for the spillway gates at various water surface elevations

(Use the same elevations for item numbers J7, K7, L, M, Q, and R)

	Elevation (meters)	Discharge (cubic meters/second)
1.	57	0
2.	60	1,619
3.	62	2,777
4.	64	4,015
5.	66.3	5,885
6.	70	9,023
7.	71.5	11,277
8.	73.36	13,762
9.	74.5	15,660

(Include the discharge rating curve if available)

K. Outlet Works Data - No outlet works

1. Type

Tunnel -
Conduit -
Weir -
Other -
None -

2. Location

Through main dam -
Through abutment -
Tunnel around end -
Other -

3. Size -

4. Total Length -

5. Shape -

6. Elevation of entrance centerline -

7. Total discharge through the outlet works for various water surface elevations

	Elevation (meters)	Discharge (cubic meters/second)
1.		
2.		
3.		
4.		
5.	N/A	N/A
6.		
7.		
8.		
9.		

(Include the discharge rating curve if available)

L. Storage capacity and elevation data for the reservoir

	Elevation (meters)	Capacity (cubic meters x 10^3)
1.	57	566
2.	60	3,500
3.	62	6,900
4.	64	12,200
5.	66.3	22,642
6.	70	56,250
7.	71.5	80,000
8.	73.36	102,264
9.	74.5	126,415

(Include the capacity-elevation curve if available)

M. Area and elevation data for the reservoir

	Elevation (meters)	Area (square meters x 10^3)
1.	57	528
2.	60	1,283
3.	62	2,208
4.	64	3,208
5.	66.3	5,981
6.	70	12,566
7.	71.5	15,000
8.	73.36	18,019
9.	74.5	20,377

(Include the area-elevation curve if available)

N. Key reservoir pool elevations and storage capacities

Pool Level	Elevation (meters)	Capacity (cubic meters x 10^3)
1. Top of Inactive	57	566
2. Top of Buffer	66.3	22,642
3. Top of Conservation	71.5	80,000
4. Top of Flood	73.36	102,264
5. Top of Dam	74.5	126,415

O. Tailwater elevations in stream at the foot of the dam

1. Maximum - 72.3 meters
2. Normal - 54 meters (Fixed head loss = .3 meters)
3. Minimum - 52 meters

P. Monthly reservoir evaporation, precipitation, and net evaporation rates

	Month	Evaporation (millimeters)	Precipitation (millimeters)	Net Evaporation (centimeters)
1.	January	25.6	27.6	1.732
2.	February	28.9	30.6	1.972
3.	March	47.1	47.2	3.294
4.	April	78.6	90.4	5.148
5.	May	103.9	76.6	8.092
6.	June	103.6	133	6.37
7.	July	86.6	383.9	- 2.857
8.	August	81.9	311.2	- 1.146
9.	September	66.1	143.6	2.302
10.	October	50.7	36.8	3.966
11.	November	30.7	27.8	2.236
12.	December	24.4	20.4	1.828

Q. Total discharge through the power penstocks at various water surface elevations

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	57	0
2.	60	0
3.	62	0
4.	64	0
5.	66.3	280
6.	70	326
7.	71.5	340
8.	73.36	340
9.	74.5	340

R. Total combined discharge capacity for all outlets, power penstocks and spillway gates at various water surface elevations

(Combine all discharge capacities listed in item numbers J7, K7, and Q)

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	57	0
2.	60	1,619
3.	62	2,777
4.	64	4,015
5.	66.3	6,165
6.	70	9,349
7.	71.5	11,617
8.	73.36	14,102
9.	74.5	16,000

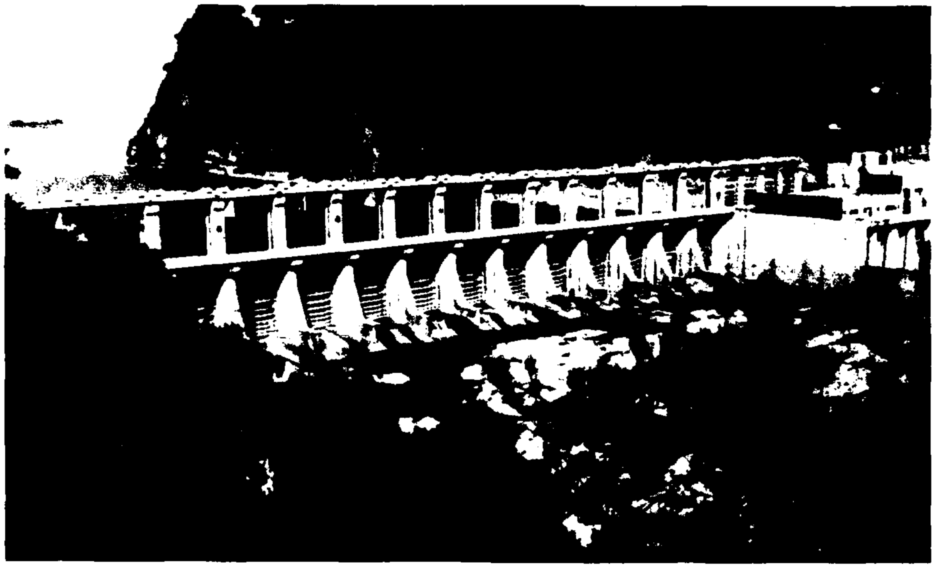

Figure 50. Frontal view of Uiam Dam and spillway gates

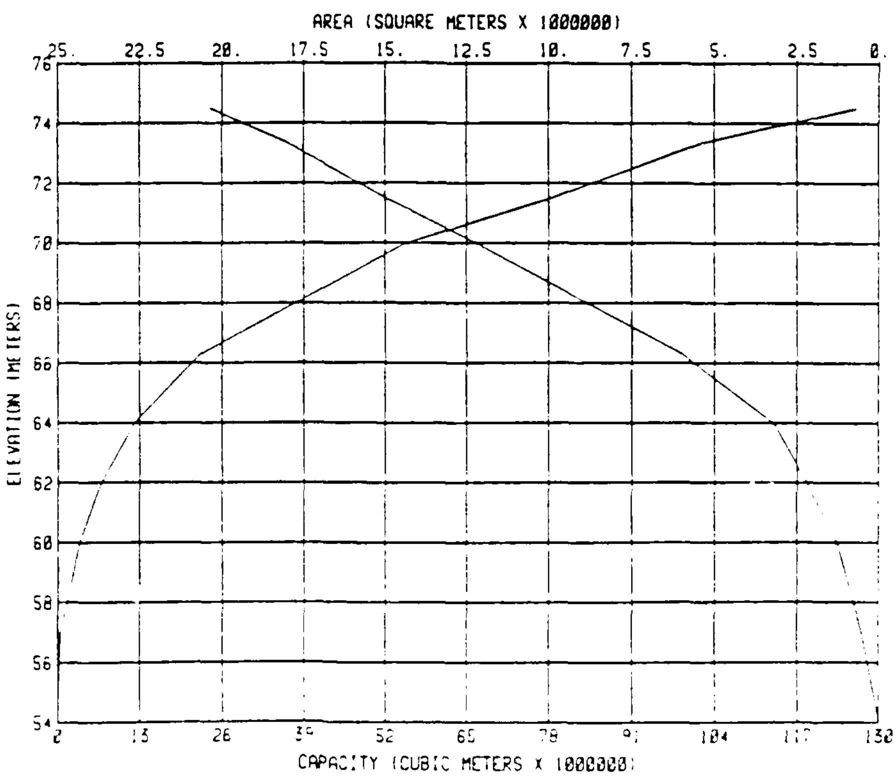

Figure 51. Area/capacity curves for Uiam Reservoir

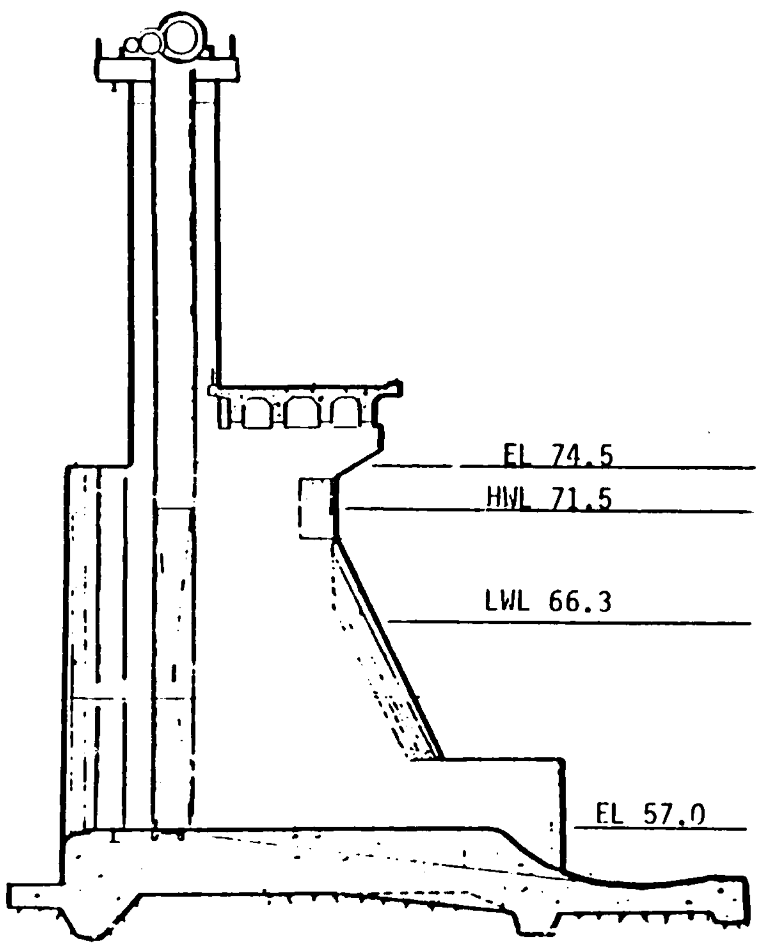

Figure 52. Cross-sectional view of Uiam Dam

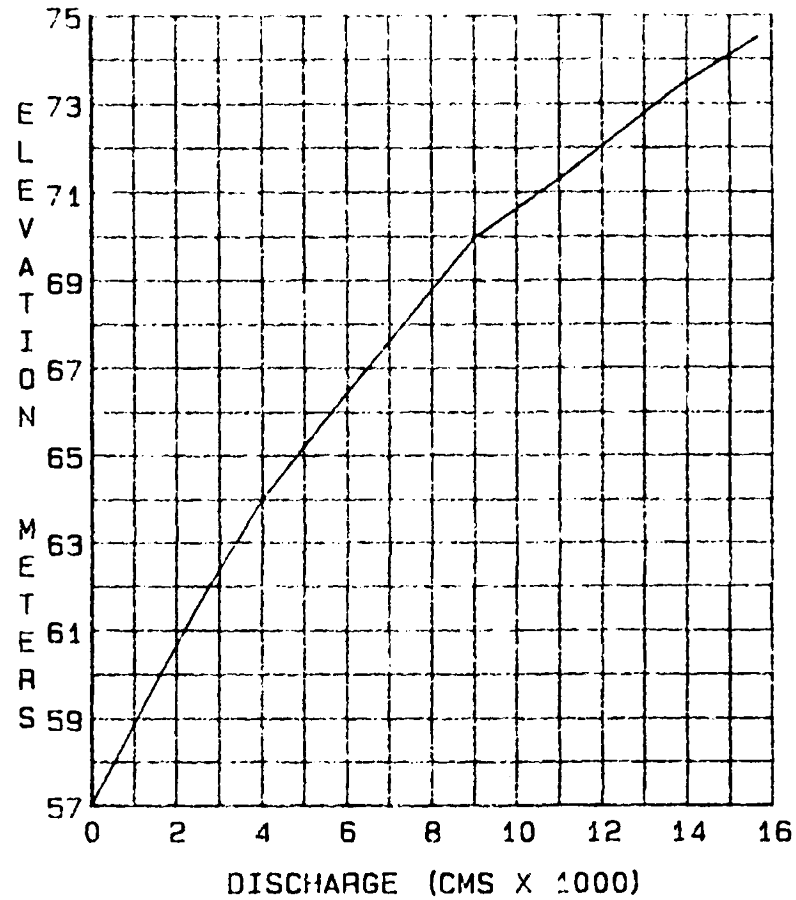

Figure 53. Spillway rating curve for Uiam Dam

Reservoir Checklist # 6 - Chongpyong

A. Name of Dam - Chongpyong
B. Location of Dam (Grid Coordinates) - CS 561758
C. Name of the river basin - Han
D. River on which the dam is located - North Han
E. Drainage area above the dam - 10,051 square kilometers
F. Year in which the dam was completed - 1943
G. Purpose(s) of the dam

Flood Control -
Water Supply - X (secondary)
Electric Power - X (primary)
Irrigation -
Navigation -
Other -

H. Type of dam and construction material

1. Type		2. Construction material	
Gravity	- X	Earth	-
Arch	-	Rockfill	-
Submerged Weir	-	Concrete	- X
Other	-	Other	-

I. Key dimensions of the dam

1. Height - 31 meters
2. Length - 407 meters
3. Volume - 250,000,000 cubic meters

J. Spillway data

1. Type

Overflow - X
Chute -
Side Channel -
Siphon -
None -

2. Crest elevation - 41 meters

3. Clear length - 288 meters

4. Type of gates		5. Number	6. Dimensions (meters) (W x L)
Rolling	-		
Vertical Lift	- X	24	12 x 10
Tainter (Radial)	-		
Drum	-		
None	-		

7. Total discharge for the spillway gates at various water surface elevations

(Use the same elevations for item numbers J7, K7, L, M, Q, and R)

	Elevation (meters)	Discharge (cubic meters/second)
1.	41	0
2.	43	1,824
3.	45	4,392
4.	46	6,096
5.	47	8,112
6.	49	12,960
7.	51	18,912
8.	52	22,464
9.	53	25,776

(Include the discharge rating curve if available)

K. Outlet Works Data - No outlet works

1. Type

Tunnel -
Conduit -
Weir -
Other -
None -

2. Location

Through main dam -
Through abutment -
Tunnel around end -
Other -

3. Size -

4. Total Length -

5. Shape -

6. Elevation of entrance centerline -

7. Total discharge through the outlet works for various water surface elevations

	Elevation (meters)	Discharge (cubic meters/second)
1.		
2.		
3.		
4.		
5.	N/A	N/A
6.		
7.		
8.		
9.		

(Include the discharge rating curve if available)

L. Storage capacity and elevation data for the reservoir

	Elevation (meters)	Capacity (cubic meters x 10^3)
1.	41	55,000
2.	43	71,086
3.	45	91,857
4.	46	105,000
5.	47	118,571
6.	49	150,200
7.	51	187,000
8.	52	203,914
9.	53	220,829

(Include the capacity-elevation curve if available)

M. Area and elevation data for the reservoir

	Elevation (meters)	Area (square meters x 10^3)
1.	41 M	5,902
2.	43 M	8,045
3.	45 M	9,023
4.	46 M	10,000
5.	47 M	10,996
6.	49 M	13,947
7.	51 M	17,250
8.	52 M	18,308
9.	53 M	20,000

(Include the area-elevation curve if available)

N. Key reservoir pool elevations and storage capacities

Pool Level	Elevation (meters)	Capacity (cubic meters x 10^3)
1. Top of Inactive	41	55,000
2. Top of Buffer	46	105,000
3. Top of Conservation	51	187,000
4. Top of Flood	52	187,000
5. Top of Dam	53	220,829

O. Tailwater elevations in stream at the foot of the dam

1. Maximum -
2. Normal - 26 meters (Fixed head loss = .6 meters)
3. Minimum -

P. Monthly reservoir evaporation, precipitation, and net evaporation rates

Month	Evaporation (millimeters)	Precipitation (millimeters)	Net Evaporation (centimeters)
1. January	24.9	26.8	1.686
2. February	31.7	25	2.42
3. March	57.4	45.8	4.366
4. April	85.5	89.9	5.853
5. May	107.9	83.1	8.297
6. June	105.2	114.2	7.094
7. July	88.2	393.4	- 2.982
8. August	89.1	312.8	- 0.474
9. September	74.4	123.1	3.747
10. October	59.7	41.2	4.734
11. November	37	30.8	2.776
12. December	25.2	18.7	1.959

Q. Total discharge through the power penstocks at various water surface elevations

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	41	0
2.	43	0
3.	45	320
4.	46	324
5.	47	326
6.	49	336
7.	51	358
8.	52	358
9.	53	358

R. Total combined discharge capacity for all outlets, power penstocks and spillway gates at various water surface elevations

(Combine all discharge capacities listed in item numbers J7, K7, and Q)

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	41	0
2.	43	1,824
3.	45	4,712
4.	46	6,420
5.	47	8,438
6.	49	13,296
7.	51	19,270
8.	52	22,822
9.	53	26,134

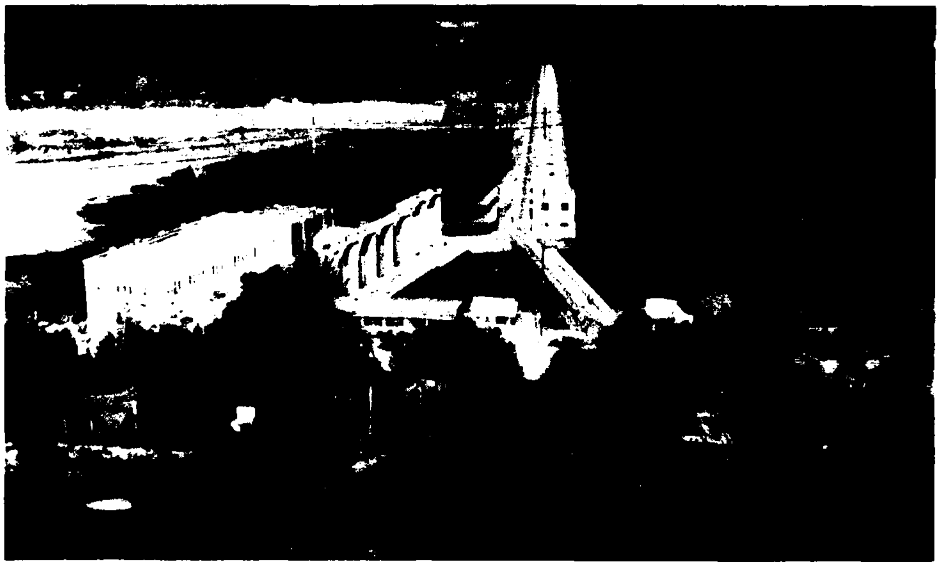

Figure 54. Side view of Chongpyong Dam and power house

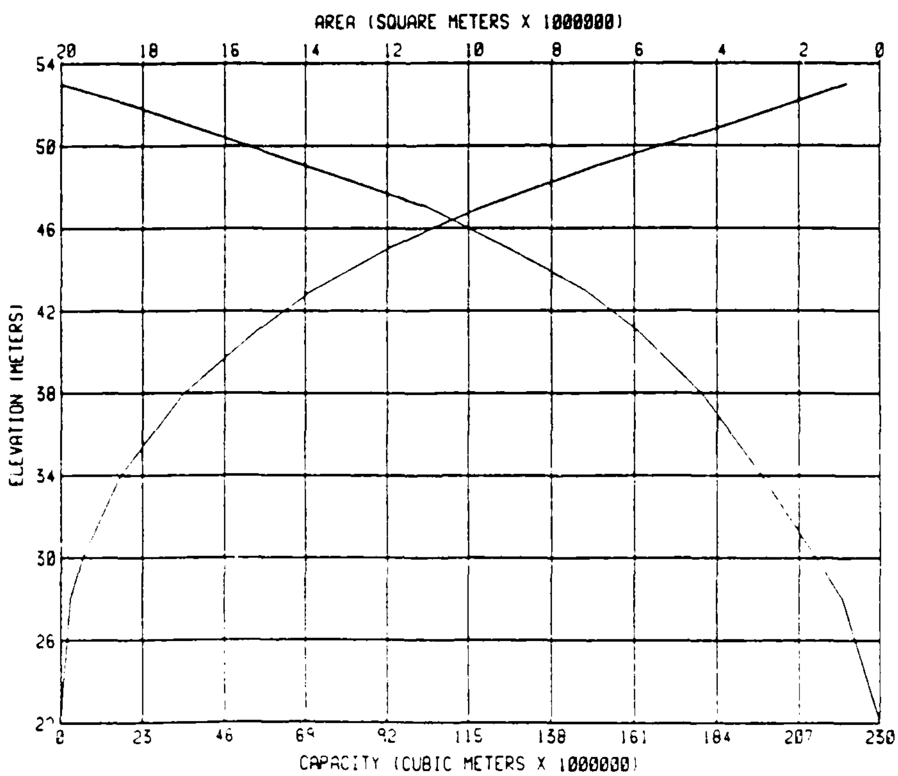

Figure 55. Area/capacity curves for Chongpyong Reservoir

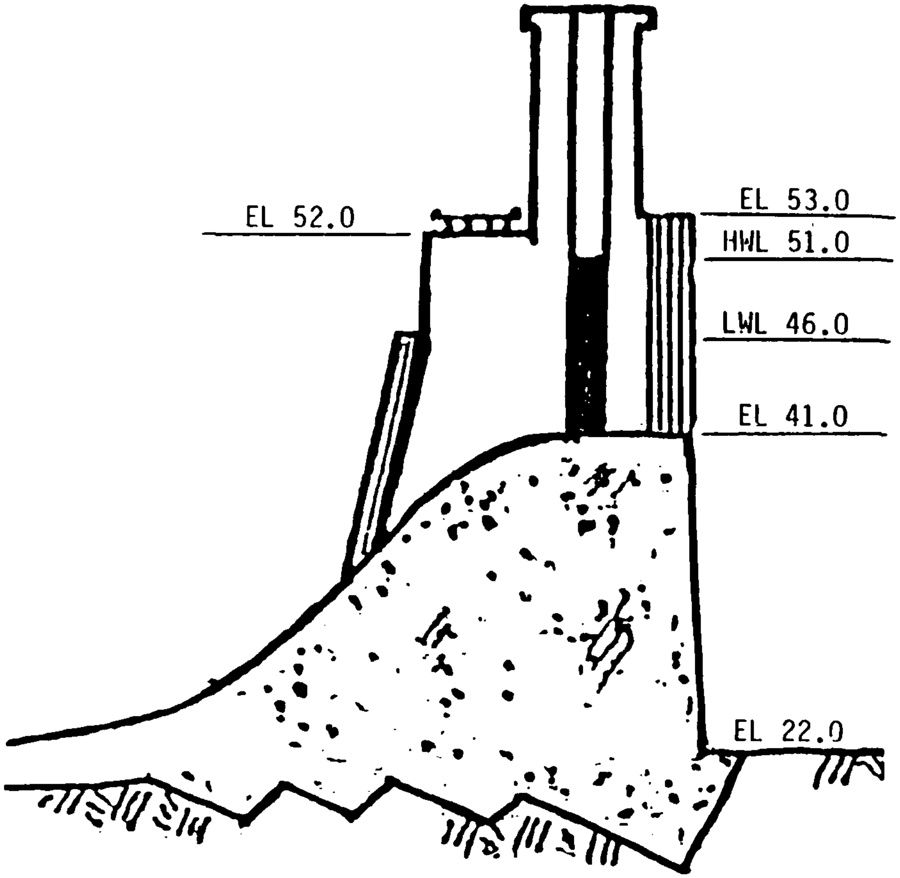

Figure 56. Cross-sectional view of Chongpyong Dam

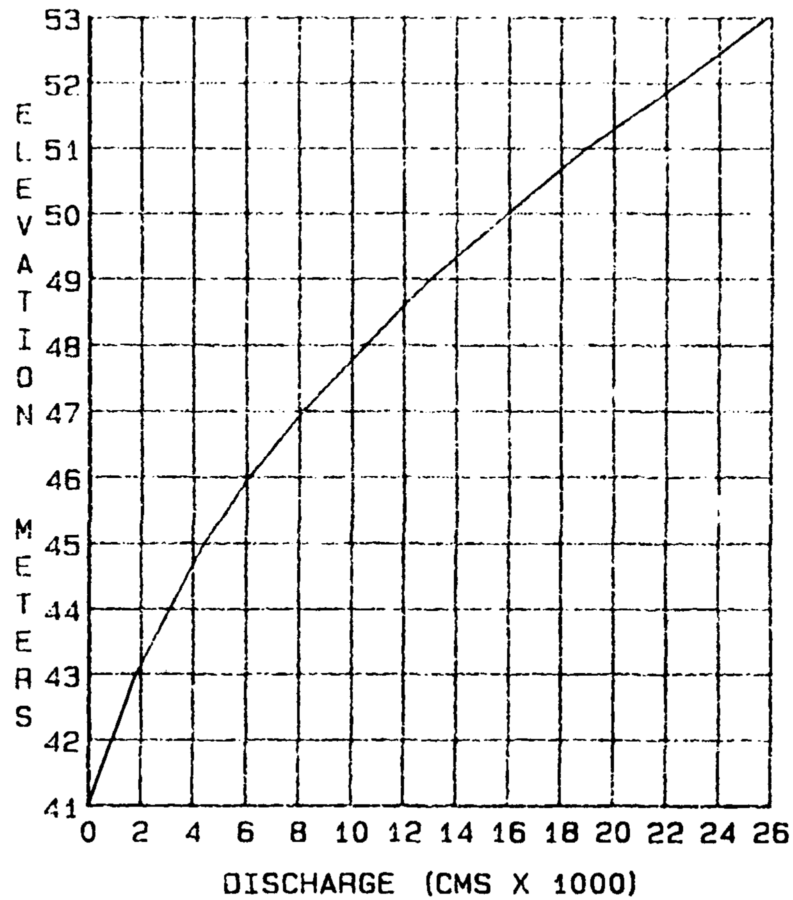

Figure 57. Spillway rating curve for Chongpyong Dam

Reservoir Checklist # 7 - Paldang

A. Name of Dam - Paldang
B. Location of Dam (Grid Coordinates) - CS 482540
C. Name of the river basin - Han
D. River on which the dam is located - Lower Han
E. Drainage area above the dam - 23,713 square kilometers
F. Year in which the dam was completed - 1973
G. Purpose(s) of the dam

Flood Control - X (secondary)
Water Supply - X (primary)
Electric Power - X (primary)
Irrigation - X (primary)
Navigation -
Other -

H. Type of dam and construction material

1. Type		2. Construction material	
Gravity	- X	Earth	-
Arch	-	Rockfill	-
Submerged Weir	-	Concrete	- X
Other	-	Other	-

I. Key dimensions of the dam

1. Height - 29 meters
2. Length - 574 meters
3. Volume - 250,000,000 cubic meters

J. Spillway data

1. Type

Overflow - X
Chute -
Side Channel -
Siphon -
None -

2. Crest elevation - 9 meters

3. Clear length - 300 meters

4. Type of gates		5. Number	6. Dimensions (meters) (W x L)
Rolling	-		
Vertical Lift	-		
Tainter (Radial)	- X	15	20 X 16
Drum	-		
None	-		

7. Total discharge for the spillway gates at various water surface elevations

(Use the same elevations for item numbers J7, K7, L, M, Q, and R)

	Elevation (meters)	Discharge (cubic meters/second)
1.	9	0
2.	15	2,500
3.	18	8,052
4.	21	15,000
5.	24	23,289
6.	25	26,000
7.	25.5	27,421
8.	29.5	38,605
9.	32	45,595

(Include the discharge rating curve if available)

K. Outlet Works Data - No outlet works

1. Type

Tunnel -
Conduit -
Weir -
Other -
None -

2. Location

Through main dam -
Through abutment -
Tunnel around end -
Other -

3. Size -

4. Total Length -

5. Shape -

6. Elevation of entrance centerline -

7. Total discharge through the outlet works for various water surface elevations

	Elevation (meters)	Discharge (cubic meters/second)
1.		
2.		
3.		
4.		
5.	N/A	N/A
6.		
7.		
8.		
9.		

(Include the discharge rating curve if available)

L. Storage capacity and elevation data for the reservoir

	Elevation (meters)	Capacity (cubic meters x 10^3)
1.	9	10,943
2.	15	34,717
3.	18	60,377
4.	21	128,301
5.	24	208,000
6.	25	244,000
7.	25.5	262,000
8.	29.5	430,000
9.	32	488,000

(Include the capacity-elevation curve if available)

M. Area and elevation data for the reservoir

	Elevation (meters)	Area (square meters x 10^3)
1.	9	787
2.	15	6,300
3.	18	13,529
4.	21	22,745
5.	24	32,157
6.	25	36,274
7.	25.5	38,800
8.	29.5	54,300
9.	32	54,700

(Include the area-elevation curve if available)

N. Key reservoir pool elevations and storage capacities

Pool Level	Elevation (meters)	Capacity (cubic meters x 10^3)
1. Top of Inactive	9	10,943
2. Top of Buffer	25	244,000
3. Top of Conservation	25.5	262,000
4. Top of Flood	29.5	430,000
5. Top of Dam	32	488,000

O. Tailwater elevations in stream at the foot of the dam

1. Maximum -
2. Normal - 10.6 meters (Fixed head loss = .3 meters)
3. Minimum -

P. Monthly reservoir evaporation, precipitation, and net evaporation rates

	Month	Evaporation (millimeters)	Precipitation (millimeters)	Net Evaporation (centimeters)
1.	January	24.9	26.8	1.686
2.	February	31.7	25	2 42
3.	March	57.4	45.8	4.366
4.	April	85.5	89.9	5.853
5.	May	107.9	83.1	8.297
6.	June	105.2	114.2	7.094
7.	July	88.2	393.4	- 2.982
8.	August	89.1	312.8	- 0.474
9.	September	74.4	123.1	3.747
10.	October	59.7	41.2	4.734
11.	November	37	30.8	2.776
12.	December	25.2	18.7	1.959

Q. Total discharge through the power penstocks at various water surface elevations

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	9	0
2.	15	0
3.	18	710
4.	21	800
5.	24	700
6.	25	648
7.	25.5	648
8.	29.5	648
9.	32	648

R. Total combined discharge capacity for all outlets, power penstocks and spillway gates at various water surface elevations

(Combine all discharge capacities listed in item numbers J7, K7, and Q)

	Elevation (meters)	Discharge (cubic meters x 10^3)
1.	9	0
2.	15	2,500
3.	18	8,762
4.	21	15,800
5.	24	23,989
6.	25	26,648
7.	25.5	28,069
8.	29.5	39,253
9.	32	46,243

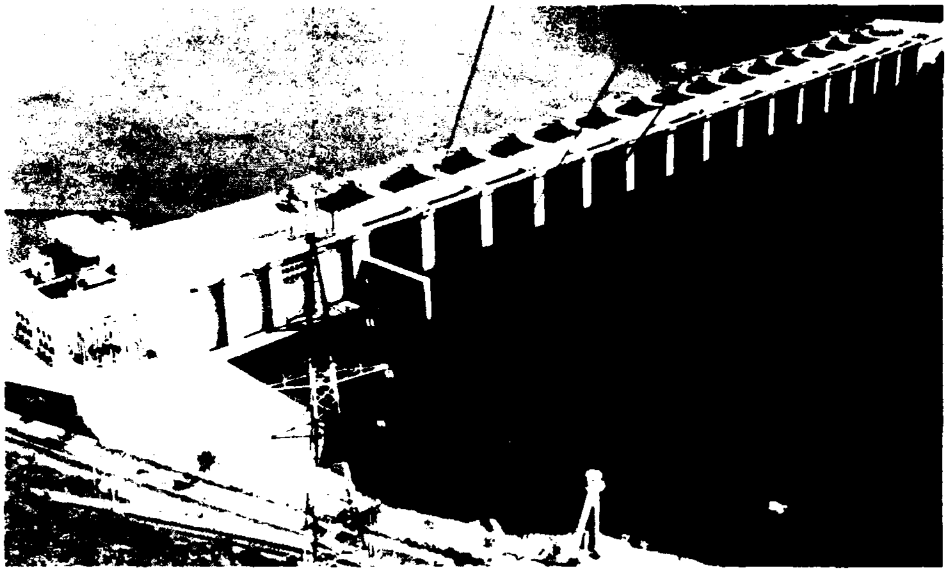

Figure 58. Frontal view of Paldang Dam and power house

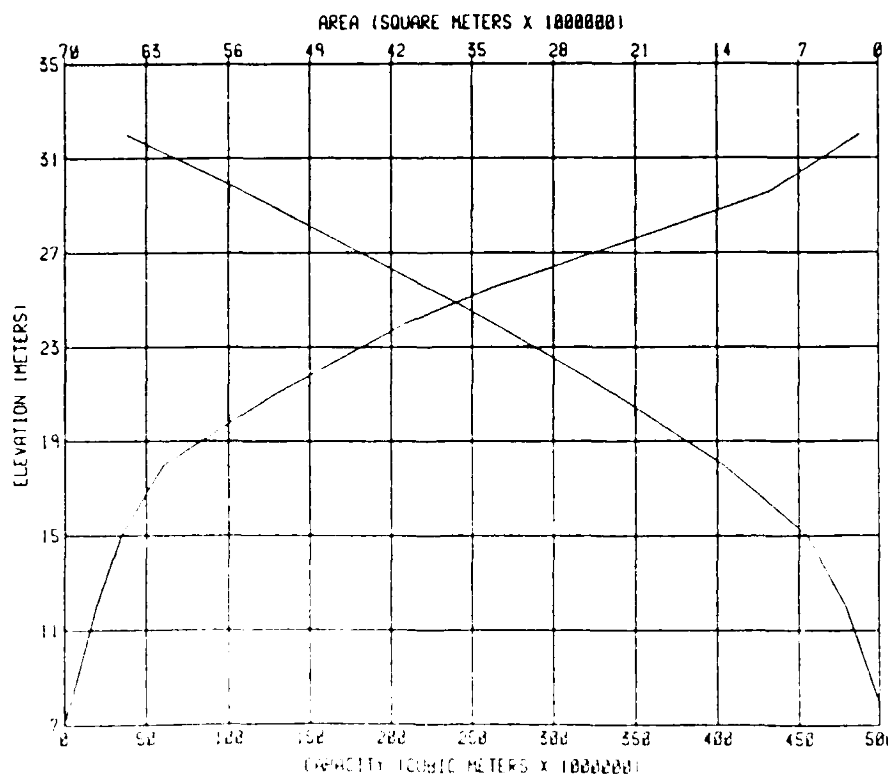

Figure 59. Area/capacity curves for Paldang Reservoir

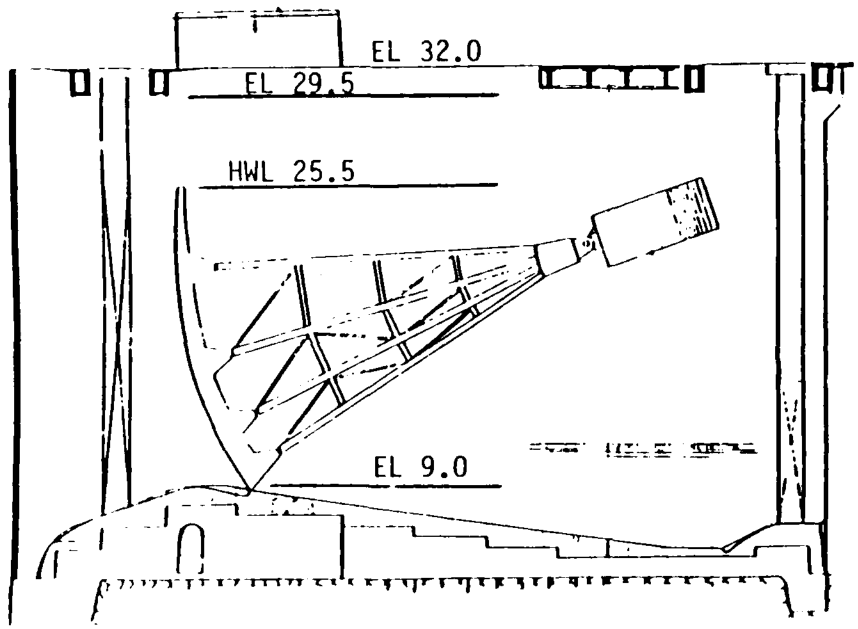

Figure 60. Cross-sectional view of Paldang Dam

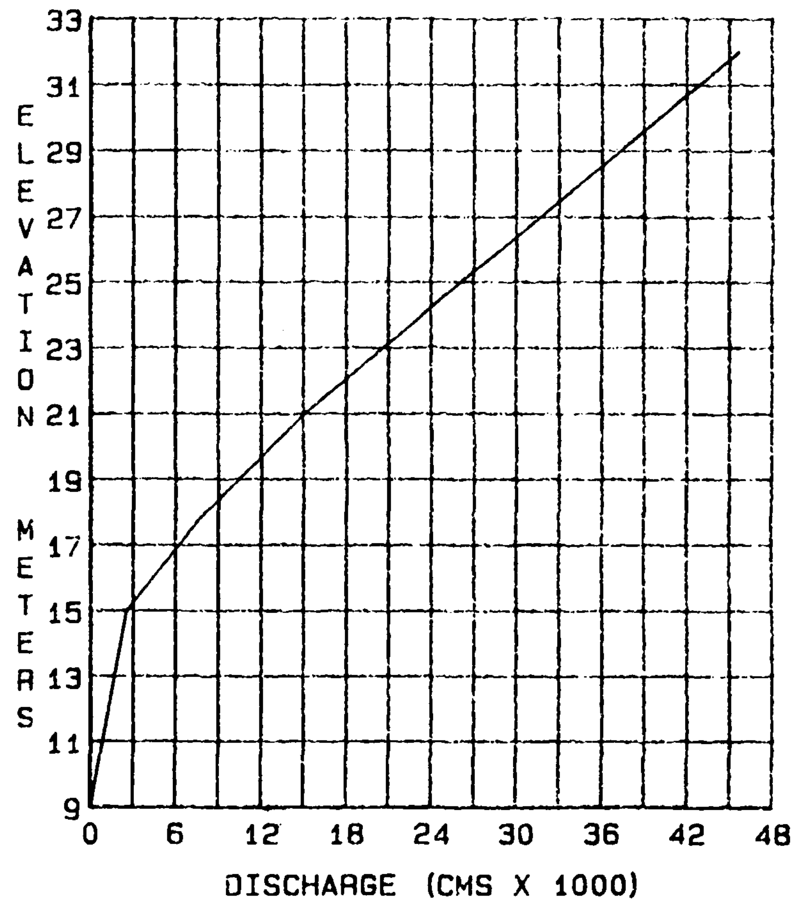

Figure 61. Spillway rating curve for Paldang Dam

The area and capacity curves depicted in the checklists above have been adjusted to reflect predicted sediment inflows into the HRB reservoir pools. No rate of sediment accumulation was predicted for the four low water reservoirs (Chunchon, Uiam, Chongpyong, and Paldang) due to their limited storage capacity and run-of-the-river type.

Average monthly evaporation and precipitation data were synthesized from a series of eleven rain gage stations and seven evaporation stations within the HRB (U.S. Army Engineer District, Far East, 1980). HEC-5 requires reservoir net evaporation (evaporation - precipitation) rates for each month specified in the model simulation. This enables the model to account for net evaporation changes in the reservoir pool level during each time increment.

APPENDIX B

CONTROL POINT CHECKLIST

Control Point Checklist - Han River Basin

A. Specify the control point (CP) identification number, system specification (reservoir/non-reservoir), flow rate record availability (yes/no) and contributing drainage area

	Alphanumeric Title	ID #	Specification (R or NR)	Flow (Y or N)	Drainage Area km^2
1.	Chungju Dam	10	R	N	6,648
2.	Hwachon Dam	20	R	Y	4,063
3.	Chunchon Dam	30	R	N	4,841
4.	Soyang Dam	40	R	Y	2,703
5.	Uiam Dam	50	R	N	7,829
6.	Chongpyong Dam	60	R	N	10,051
7.	Paldang Dam	70	R	Y	23,713
8.	Chungju Gage	05	NR	Y	6,689
9.	Yoju Bridge/Gage	15	NR	Y	11,132
10.	Chunchon Gage	25	NR	N	8,016
11.	Misari Island	35	NR	N	23,879
12.	Indogyo Gage	45	NR	N	25,047
13.	Han River Bridge	55	NR	N	25,349
14.	Yellow Sea	00	NR	N	26,200

(Note - control point 00 (Yellow Sea) is the last node in the HRB model and will only be referenced when required.)

B. Determine the corresponding control point and area ratio factor that will be used to provide flow rates at all control points listed above without flow records

	ID # of CP w/o Flow Records	ID # of CP with Flow Records	Area Ratio Factor		Area Ratio Calculations
1.	10	05	.994	=	(6648/6689)
2.	25	20	1.850	=	(8016/4063)
3.	30	20	1.191	=	(4841/4063)
4.	35	70	1.007	=	(23879/23713)
5.	45	70	1.056	=	(25047/23713)
6.	50	20	1.927	=	(7829/4063)
7.	55	70	1.069	=	(25349/23713)
8.	60	20	2.474	=	(10051/4063)

C. Determine the diversion requirement forecast for municipal, industrial, and irrigation withdrawals (monthly schedule) at all necessary control points

CP ID #	05	15	25	35	55	70
	Upper South Han	Middle South Han	Upper North Han	<<<<	Lower Han	>>>>
Month	<<<<<<<<<<<<<<<		Flow Rates in CMS		>>>>>>>>>>>>>>	
Jan	3.07	0.42	1.20	0.00	39.68	31.63
Feb	3.07	0.42	1.20	0.00	39.68	31.63
Mar	3.07	0.42	1.20	0.00	39.68	31.63
Apr	8.60	2.51	5.26	30.06	40.49	31.63
May	15.55	7.09	5.26	69.97	41.57	31.63
Jun	19.95	10.97	5.26	49.45	41.02	31.63
Jul	9.88	7.13	5.26	41.87	40.81	31.63
Aug	16.12	9.90	5.26	50.30	41.03	31.63
Sep	9.88	4.48	5.26	18.26	40.17	31.63
Oct	12.36	3.58	5.26	20.79	40.24	31.63
Nov	3.07	0.42	1.20	0.00	39.68	31.63
Dec	3.07	0.42	1.20	0.00	39.68	31.63

D. Determine the control point and percentage of diverted flow that returns at that location for each diversion specified above

CP ID # for Diversion	CP ID # for Return Flow	Percentage of Diversion that Returns to Stream
05	15	55.1
15	70	51.6
25	50	55.0
35	45	64.8
55	00	50.0
70	55	65.0

E. Determine the maximum flow (nondamaging capacity), average 24-hour power release (reservoir control points), minimum required flow, maximum diversion flow, and peak minimum desired flow for each control point (all flows are in cubic meters/second)

CP ID #	Maximum Non-Flood Flow	Average 24-Hour Power Release	Minimum Required Flow	Maximum Diversion Flow	Peak Minimum Desired Flow
05	1500	None	13.7	19.65	33.65
10	1500	84.7	N/A	None	84.7
15	2000	None	24.4	10.97	36.37
20	800	59.0	N/A	None	59.0
25	5275	None	38.3	5.26	43.56
30	2000	71.0	N/A	None	71.0
35	4000	None	114.7	41.57	156.27
40	600	52.2	N/A	None	52.2
45	4000	None	127.7	None	127.7
50	2000	130.0	N/A	None	130.0
55	4000	None	100.8	69.97	170.77
60	2000	80.7	N/A	None	80.7
70	4000	166.7	N/A	31.63	166.7

Reservoir control points in the HRB were identified on the basis of three rules: (1) reservoir drawdown strategies identified in the military staff input, (2) induced flooding potential (storage volume), and (3) availability of historical flow records. Only three reservoirs in the HRB system had flow records available, these included Hwachon (CP-20), Soyang (CP-40), and Paldang (CP-70).

Non-reservoir control points were identified on the basis of four rules: (1) availability of flow records, (2) diversion location, (3) return flow location, and (4) river crossing sites identified in the staff input analysis. Flow records at the Chungju gage (CP-05) were used to establish the inflow data points for the only external node in the system without available flow records, (Chungju reservoir, CP-10). HEC-5 options include the ability to create flow records at specified locations by multiplying known flows by a ratio of the corresponding drainage areas. The area ratio factor established between the Chungju reservoir (CP-10) and the Chungju gage (CP-05) was equal to 0.994, a calculation based on drainage areas contributing to flow at the respective control point locations. Using this ratio factor, flow records were established at the Chungju reservoir equal to 99.4 percent of the measured flow rates at the Chungju gage for each time period. Non-reservoir control points 05, 15, 25, 35, and 55 were all chosen on the basis of diversion locations for municipal and industrial water supply and irrigation. Flow records were available for five of the thirteen control points in the study area (CP-05, CP-15, CP-20, CP-40, and CP-70). Four locations were considered critical within the basin; these points were the external nodes (Hwachon, Soyang, and Chungju Reservoirs) and the confluence of the North and South Han Rivers. External node points are extremely important to the model simulation sequence because they directly influence the regulation and operation of internal node points at all downstream locations below the reservoirs. Although flow records were available for only three of the four critical locations, area ratio factors were used to create realistic flow records at the Chungju reservoir and all other necessary control points.

Minimum required flows at all non-reservoir control points were a time-dependent variable equal to municipal and industrial water supply requirements plus instream uses (fish, wildlife and, environmental constraints). Minimum required flows at reservoir control points were based on the operation of the dam for hydroelectric power generation (average 24-hour power release).

Minimum desired flows at non-reservoir control points were a time-dependent variable equal to the total diversion flow plus the minimum required flow. Minimum desired flows at all reservoir control points were set equal to the minimum required flows established for hydropower generation. Since hydropower requirements at each reservoir were established in the input data deck, HEC-5 automatically calculated the minimum required flow as part of the model simulation process.

Minimum required flows in the Seoul area (Indogyo gage, CP-45) were established based on the flow rate necessary to prevent salt water intrusion from tidal fluctuations created by the Han River estuary.

APPENDIX C

HYDROPOWER CHECKLIST

Hydropower Checklist - Han River Basin

A. Hydropower plant operating characteristics

Reservoir Name	Overload Ratio	Power Plant Efficiency (%)	Generating Capacity (kW)	Size & # of Units (kW x 10^3)	Rated Head (m)
1. Chungju	1.15	87.4	400,000	100.0 x 4	57.5
2. Hwachon	1.15	80.0	108,000	27.0 x 4	74.5
3. Chunchon	1.15	89.6	57,600	28.2 x 2	28.8
4. Soyang	1.15	83.1	200,000	100.0 x 2	90.0
5. Uiam	1.15	78.7	45,000	22.5 x 2	17.2
6. Chongpyong	1.15	83.8	79,600	40.0 x 1	26.02
				19.8 x 2	26.02
7. Paldang	1.15	87.0	80,000	20.0 x 4	11.8

B. Determining the hydropower plant penstock discharge capacity, average tailwater elevation, hydraulic head loss, and downstream reservoir control point number that affects the tailwater elevation

Reservoir Name	Maximum Penstock Capacity (cms)	Average Tailwater Elevation (m)	Hydraulic Head Loss (m)	Tailwater Elevation Affected (CP-#)
1. Chungju	784.0	71.3	3.0	N/A
2. Hwachon	138.75	103.0	3.5	30
3. Chunchon	247.0	74.0	0.2	50
4. Soyang	250.8	80.7	3.7	N/A
5. Uiam	340.0	54.0	0.3	N/A
6. Chongpyong	370.0	26.0	0.6	70
7. Paldang	800.0	10.6	0.3	N/A

C. Monthly at-site power requirements

Reservoir Name	Power Requirements (kWh x 10^3)					
	Jan	Feb	Mar	Apr	May	Jun
1. Chungju	41,223	37,233	41,233	39,893	41,233	39,893
2. Hwachon	19,081	17,545	19,081	23,051	33,296	41,492
3. Chunchon	9,528	8,729	9,528	11,987	17,150	21,207
4. Soyang	43,541	39,187	40,148	33,681	38,675	38,419
5. Uiam	10,957	10,050	10,957	13,821	18,103	21,489
6. Chongpyong	18,103	16,935	18,103	22,129	30,489	34,116
7. Paldang	14,292	13,370	20,485	39,648	33,348	32,272

Reservoir Name	Power Requirements (kWh x 10^3) Jul	Aug	Sep	Oct	Nov	Dec
1. Chungju	41,223	41,233	39,893	41,233	39,893	41,233
2. Hwachon	66,721	66,721	50,713	28,558	19,081	17,545
3. Chunchon	35,730	35,730	25,356	14,768	11,987	12,386
4. Soyang	36,242	29,635	37,907	39,174	35,537	36,754
5. Uiam	24,296	23,343	22,129	15,245	12,909	13,339
6. Chongpyong	38,112	37,635	35,499	24,773	23,051	23,820
7. Paldang	47,639	47,639	43,798	19,056	18,902	19,056

D. Hydropower peaking capability

(1) No data available = 0
(2) Peaking capability versus reservoir storage relationship = 1
(3) Peaking capability versus reservoir release relationship = 2
(4) Peaking capability versus reservoir operating head = 3

When specifying the operating rule for peaking capability, include hydropower tailwater curve versus reservoir outflow or hydropower efficiencies versus reservoir storage.

1. Reservoir name - Chungju
   a. Peaking capability option = 3 (operating head)
   b. Hydropower efficiency versus reservoir storage - Yes
   c. Tailwater elevation versus reservoir release - Yes

2. Reservoir name - Hwachon
   a. Peaking capability option = 3 (operating head)
   b. Hydropower efficiency versus reservoir storage - No
   b. Tailwater elevation versus reservoir release - No

3. Reservoir name - Chunchon
   a. Peaking capability option = 0 (no data available)
   b. Hydropower efficiency versus reservoir storage - No
   b. Tailwater elevation versus reservoir release - No

4. Reservoir name - Soyang
   a. Peaking capability option = 3 (operating head)
   b. Hydropower efficiency versus reservoir storage - No
   b. Tailwater elevation versus reservoir release - No

5. Reservoir name - Uiam
   a. Peaking capability option = 3 (operating head)
   b. Hydropower efficiency versus reservoir storage - No
   b. Tailwater elevation versus reservoir release - No

6. Reservoir name - Chongpyong
   a. Peaking capability option = 0 (no data available)
   b. Hydropower efficiency versus reservoir storage - No
   b. Tailwater elevation versus reservoir release - No

7. Reservoir name - Paldang
   a. Peaking capability option = 0 (no data available)
   b. Hydropower efficiency versus reservoir storage - No
   b. Tailwater elevation versus reservoir release - No

Chungju Reservoir (CP-10)

Maximum Peaking Capability (kW)	Reservoir Operating Head (m)	Hydropower Efficiency (%)	Tailwater Elevation (m)	Reservoir Release (cms)
210,000	38.3	86.0	64.0	0.0
236,000	41.0	88.0	65.0	70.0
260,000	43.0	90.0	70.0	71.0
276,000	45.0	90.7	71.0	75.6
300,000	47.0	91.2	71.5	108.0
330,000	50.8	92.0	72.5	216.0
360,000	52.5	92.7	74.5	432.0
400,000	57.5	94.0	76.0	540.0
400,000	60.8	92.0	76.0	540.0
400,000	70.5	92.0	76.0	540.0

Hwachon Reservoir (CP-10)		Soyang Reservoir (CP-40)		Uiam Reservoir (CP-50)	
Maximum Peaking Capability (kW)	Reservoir Operating Head (m)	Maximum Peaking Capability (kW)	Reservoir Operating Head (m)	Maximum Peaking Capability (kW)	Reservoir Operating Head (m)
62,400	52.0	117,860	65.6	30,000	12.0
70,000	56.0	129,714	70.6	45,000	15.9
80,800	60.0	150,000	75.6	45,000	17.2
89,600	64.0	164,286	80.6	45,000	20.5
92,800	66.0	180,428	85.6		
96,800	68.0	200,000	90.0		
100,400	70.0	200,000	95.6		
104,000	72.0	200,000	100.6		
108,000	74.0	200,000	110.0		
108,000	76.7	200,000	118.6		

Chunchon Reservoir (CP-30)		Chongpyong Reservoir (CP-60)		Paldang Reservoir (CP-70)	
Maximum Peaking Capability (kW)	Reservoir Operating Head (m)	Maximum Peaking Capability (kW)	Reservoir Operating Head (m)	Maximum Peaking Capability (kW)	Reservoir Operating Head (m)
N/A		N/A		N/A	

The HRB provides the majority of the hydropower capacity for South Korea with 970.2 MW of installed capacity; this power source is used as a peaking reserve to maintain power system operating stability. The Korea Electric Company (KEPCO) supplies the majority of electrical power in South Korea, utilizing a nationwide grid connecting thermal (68%), nuclear (6.3%), internal combustion (13%), and hydropower (12.7%) generating facilities.

APPENDIX D

TIME SERIES INFLOW DATA CHECKLIST

Time Series Inflow Data Checklist

A. Identify control points within the river basin having available flow records. For each control point include the flow period length, start and end dates, missing observations, total number of periods, and location of the CP node within the model simulation (internal or external).

CP #	Flow Period Length	Start Date	End Date	Missing Observations	Total No. of Periods	CP Node Location
05	Monthly	1917	1972	1941-1955	492	Internal
15	Monthly	1917	1972	1941-1955	492	Internal
20	Monthly	1917	1972	1941-1955	492	External
40	Monthly	1917	1972	1941-1955	492	External
70	Monthly	1917	1972	1941-1955	492	Internal

B. Determine the category of time series flow (incremental local flows, cumulative local flows, or natural flows) that corresponds to each control point listed above

CP #	Time Series Flow Category
05	Natural unregulated flows
15	Natural unregulated flows
20	Natural unregulated flows
40	Natural unregulated flows
70	Natural unregulated flows

C. List the time series inflow data for each control point listed in step A. All flow rates are measured in cubic meters per second.

(Complete streamflow records not listed below are provided for all other periods in Appendix F.)

Chungju Gage

CP #	Year	Jan	Feb	Mar	Apr	May	Jun
05	1917	9.20	10.20	26.3	40.9	73.6	20.0
05	1918	5.63	9.16	20.0	40.8	92.7	104.6
	.						
	.						
	.						
05	1971	22.04	25.83	69.84	83.46	135.44	44.55
05	1972	26.42	45.99	225.72	269.58	116.30	26.00

Chungju Gage (continued)

CP #	Year	Jul	Aug	Sep	Oct	Nov	Dec
05	1917	378.10	53.60	380.50	25.80	12.90	7.71
05	1918	931.60	282.36	43.60	21.10	25.40	14.80
	.						
	.						
	.						
05	1971	766.58	391.23	120.45	43.50	22.25	12.64
05	1972	78.29	1197.90	507.23	153.52	256.20	113.71

Yoju Bridge/Gage

CP #	Year	Jan	Feb	Mar	Apr	May	Jun
15	1917	23.10	17.30	37.40	55.00	105.9	30.10
15	1918	12.10	14.70	43.20	61.20	119.2	130.70
	.						
	.						
	.						
15	1971	39.50	38.29	148.10	153.06	214.99	81.75
15	1972	47.02	78.29	258.91	361.13	183.50	55.32

CP #	Year	Jul	Aug	Sep	Oct	Nov	Dec
15	1917	433.50	116.10	534.20	46.90	28.50	19.00
15	1918	1015.00	484.50	74.60	38.40	44.30	29.20
	.						
	.						
	.						
15	1971	1236.40	612.39	235.77	93.44	48.24	33.66
15	1972	134.24	1639.60	677.07	313.29	368.60	260.06

Hwachon Reservoir

CP #	Year	Jan	Feb	Mar	Apr	May	Jun
20	1917	10.40	10.10	16.70	23.70	53.60	11.30
20	1918	8.30	10.80	19.00	27.80	28.30	22.30
	.						
	.						
	.						
20	1971	13.00	14.00	34.40	51.20	69.10	44.50
20	1972	15.30	18.40	81.90	130.60	29.80	22.60

Hwachon Reservoir (continued)

CP #	Year	Jul	Aug	Sep	Oct	Nov	Dec
20	1917	117.60	71.30	307.10	33.90	19.00	12.60
20	1918	325.90	234.80	56.90	22.20	21.30	14.40
	.						
	.						
	.						
20	1971	401.70	261.70	209.00	53.10	28.40	17.50
20	1972	132.00	773.40	168.30	57.20	85.70	49.10

Soyang Reservoir

CP #	Year	Jan	Feb	Mar	Apr	May	Jun
40	1917	6.80	6.40	11.50	18.70	31.40	8.10
40	1918	6.20	7.90	10.30	14.00	20.70	15.20
	.						
	.						
	.						
40	1971	11.30	10.30	29.30	43.70	67.00	29.30
40	1972	12.70	19.00	83.00	142.00	27.00	13.00

CP #	Year	Jul	Aug	Sep	Oct	Nov	Dec
40	1917	29.30	48.70	152.40	18.30	12.80	9.00
40	1918	172.10	209.50	30.80	13.70	12.60	9.50
	.						
	.						
	.						
40	1971	262.20	227.00	114.80	31.50	18.10	14.00
40	1972	25.00	60.70	83.00	39.00	22.00	4.00

Paldang Reservoir

CP #	Year	Jan	Feb	Mar	Apr	May	Jun
70	1917	70.50	41.90	79.20	105.70	220.20	65.80
70	1918	34.30	34.20	102.70	127.20	198.10	227.10
	.						
	.						
	.						
70	1971	97.20	134.30	621.40	292.10	283.70	444.00
70	1972	154.60	220.40	284.40	363.10	241.40	162.90

Paldang Reservoir (continued)

CP #	Year	Jul	Aug	Sep	Oct	Nov	Dec
70	1917	651.70	330.20	1147.00	120.20	82.00	57.30
70	1918	1375.00	1186.00	182.20	98.10	109.50	78.70
	.						
	.						
	.						
70	1971	4728.00	1267.00	1653.00	287.40	264.60	227.10
70	1972	963.00	1044.00	1021.00	192.70	161.30	145.10

All time series inflow data for the HRB model simulation were obtained from the Far East District of the Corps of Engineers. Streamflow data synthesized from Korean records were not available for all monthly periods; therefore, Corps of Engineer personnel used the HEC-4 Monthly Streamflow Simulation computer program and non-linear regression methods to fit unknown data points with best-fit approximations. Streamflow records were synthetically generated at two control point locations: (1) Soyang Reservoir (1956-1967), and (2) Paldang Reservoir/Goan Gage (1967-1972). Additionally, Korean records provided streamflow in the form of daily stage records at gaging locations. These records were converted to flow rates using discharge conversion equations. Correlations were made between gaging stations to check agreement and confidence in the stream flow estimates (U.S. Army Engineer District, Far East, 1980).

APPENDIX E

MAP AND BASIN CHECKLIST

Map and Basin Checklist

A. Determine the monthly evaporation and precipitation rates over the basin area.

Basin Monthly Net Evaporation (millimeters)

Jan	Feb	Mar	Apr	May	Jun
17.5	22.4	37.2	53.8	80.3	66.2

Jul	Aug	Sep	Oct	Nov	Dec
-27.3	-11.4	27.4	42.1	25.2	19.7

B. Determine the key land use areas and water resource projects within the river basin. Attach map if available.

1. Existing irrigable land

   a. Chungju area
   b. Yoju area
   c. Chunchon area
   d. Paldang Reservoir area
   e. Hangang barrage and lower Han River bridge area

2. Potential irrigable land

   a. Chungju area
   b. Yoju area
   c. Hangang Barrage and lower Han River Bridge area

3. Tideland areas

   a. Hangang Barrage and lower Han River Bridge
   b. Inchon area
   c. Suwon area (east)

4. Existing Dams and hydropower plants

   a. Chungju Dam and power plant
   b. Hwachon Dam and power plant
   c. Chunchon Dam and power plant
   d. Soyang Dam and power plant
   e. Uiam Dam and power plant
   f. Chongpyong Dam and power plant
   g. Paldang Dam and power plant
   h. Koesan Dam and power plant

5. General map of the Han River Basin is depicted in Figure 14 of the main text

APPENDIX F

BASE LINE SYSTEM FOR THE HAN RIVER BASIN

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T1 MILITARY APPLICATIONS OF RESERVOIR OPERATIONS  (PHASE I - BASE CONDITIONS)
T2 HAN RIVER CASE STUDY (KOREAN THEATER OF OPERATIONS)
T3 SYSTEM DEMAND SIMULATION (HYDROPOWER, WATER SUPPLY (M&I) & IRRIGATION)
J1       1        1        5        3        4        2        0        0        0
J2       0        1        0        0        0        0        0
J3       2        0        0        0        0       20        0        0
J4       0        0        1        0        0        0     64.7     27.7        0        0
J6    17.5     22.4     37.2     53.8     80.3     66.2    -27.3    -11.4     27.4     42.1
J6    25.2     19.7
J8   10.09    10.10    10.11    10.22    10.15    10.16    10.23
J8   20.09    20.10    20.11    20.22    20.15    20.16    20.23
J8   30.09    30.10    30.11    30.22    30.15    30.16    30.23
J8   40.09    40.10    40.11    40.22    40.15    40.16    40.23
J8   50.09    50.10    50.11    50.22    50.15    50.16    50.23
J8   60.09    60.10    60.11    60.22    60.15    60.16    60.23
J8   70.09    70.10    70.11    70.22    70.15    70.16    70.23
J8    5.04     5.07     5.08     5.30     5.31    15.04    15.07    15.08    15.30    15.31
J8   25.04    25.07    25.08    25.30    25.31    35.04    35.07    35.08    35.30    35.31
J8   70.30    70.31    45.04    45.07    45.08    55.04    55.07    55.08    55.30    55.31
RL      10  2330000   510000   510000  2330000  2625000  2900000
RO       3        5       15       70
RS       9    70000   510000   935000  1100000  1505000  1850000  2330000  2625000  2900000
RQ       9        0       41      705      735     3878     7763    13589    18067    21086
RA       9     6200    32000    48200    53600    55000    73200    83200    93000    99000
RE       9       86      110      120      123      130      135      141      145    147.5
R3    1.64    2.282    3.625    5.373    8.378    7.193    2.058    1.974    2.764    3.786
R3   2.025    1.414
P1      10   400000     1.15        3        0        0       -1        3
P2       0      784        0        0
PR   41223    37233    41223    39893    41223    39893    41223    41223    39893    41223
PR   39893    41223        0        0
PQ       0      5.4       54     75.6      108      216      432      540     1339
PT      64       65       70       71     71.5     72.5     74.5       76     80.7
PP210000     236000   260000   276000   300000   330000   360000   400000   400000   400000
PS    38.3       41       43       45       47     50.8     52.5     57.5     60.8     70.5
PE     .86      .88       .9     .907     .912      .92     .927      .94      .92      .92
CP      10     1500        0        0        0        0
IDCHUNGJU DAM
C1      05     .994        0        0
RT      10       05        0      1.2       .5        0        0        0
CP      05     1500    33.65    -13.7        0        0
IDCHUNGJU GAGE
RT      05       15        0      1.2       .5        0        0        0
DR      05       15        0      1.2       .5     .551        1        0        0
QD      12     3.07     3.07     3.07     8.60    15.55    19.95     9.88    16.12     9.88
QD   12.36     3.07     3.07
QM   16.77    16.77    16.77     22.3    29.25    33.65    23.58    29.82    23.58    26.06
QM   16.77    16.77
CP      15     2000    36.37    -25.4        0        0
IDYOJU BRIDGE
RT      15       70        0      1.2       .5        0        0        0
DR      15       70        0      1.2       .5     .516        1        0        0
QD      12     0.42     0.42     0.42     2.51     7.09    10.97     7.13     9.90     4.48
QD    3.58     0.42     0.42
QM   25.82    25.82    25.82    27.91    32.49    36.37    32.53    35.30    29.88    28.98
QM   25.82    25.82
RL      20   905000   277000   277000   905000   930000  1025000
RO       0
RS       9   126000   277000   650000   710000   771000   840000   905000   980000  1025000
RQ       9        0      145      165      408     1571     3461     5847     7675     8738
RA       9     8000    15200    30000    32500    34000    36200    39000    41500    43500
RE       9    145.2    156.8      173      175      177      179      181      183    184.5
R3   1.824    2.338    3.509    5.154    7.693    6.399   -2.345   -1.797    2.175    3.919
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```
R3 2.531    2.109
P1     20  108000     1.15         3       103        30        .8       3.5
P2      0  138.75        0         0
PR 19081    17545    19081     23051     33296     41492     55721     56721     50713     28558
PR 23051    23820        0         0
PP 62400    70000    80800     89600     92800     96800    100400    104000    108000    108000
PS     52      56       60        64        66        68        70        72        74      76.7
CP     20     800        0         0         0         0
IDHWACHON DAM
RT     20      30        0       1.2        .5         0         0         0
RL     30  150000    89821     89821    150000    150000    240000
RO      0
RS      8   37383    85981     89821    111062    135902    150000    220000    240000
RQ      8       0     3060      5274      7985     11154     12828     16128     19428
RA      8    5278     7830      9692     11549     13290     14150     15700     17449
RE      8    90.8       96        98       100       102       103       105       107
R3 1.824    2.338    3.509     5.154     7.698     5.399    -2.345    -1.797     2.175     3.919
R3 2.531    2.109
P1     30   57600     1.15         0        74        50      .895        .2
P2      0     228        0         0
PR  9528     8729     9528     11987     17150     21207     35730     35730     25355     14768
PR 11987    12386        0         0
CP     30    2000        0         0         0         0
IDCHUNCHON DAM
C1     20   1.191        0         0
RT     30      25        0       1.2        .5         0         0         0
RL     40 2490000   650000    650000   2490000   2900000   3200000
RO      2      25       70
RS      9  165000   650000    925000   1990000   2150000   2260000   2490000   2900000   3200000
RQ      9    41.5      271       288       289       702      1367      2980      5915      9437
RA      9    9300    23000     28000     60000     53000     65300     69500     75000     80200
RE      9     120      150       160     185.5       188       190     193.5       198       203
R3 1.732    1.972    3.294     5.148     8.092      6.37    -2.857    -1.146     2.302     3.966
R3 2.236    1.828
P1     40  200000     1.13         3      80.7         0      .831       3.7
P2      0   250.8        0         0
PR 43541    39187    40148     33681     38575     38419     36242     39635     37907     39174
PR 35537    36754        0         0
PP117860   129714   150000    164286    180428    200000    200000    200000    200000    200000
PS   65.6    70.6     75.6      80.6      85.6        90      95.5     100.6       110     118.6
CP     40     600        0         0         0         0
IDSOYANG DAM
RT     40      25        0       1.2        .5         0         0         0
CP     25    5275    43.56     -38.3         0         0
IDCHUNCHON GAGE
C1     20   1.850        0         0
RT     25      50        0       1.2        .5         0         0         0
DR     25      50        0       1.2        .5       .55         1         0         0
QD     12     1.2      1.2       1.2      5.26      5.26      5.26      5.26      5.25      5.26
QD   5.26     1.2      1.2
QM   39.5    39.5     39.5     43.56     43.56     43.56     43.55     43.56     43.55     43.56
QM   39.5    39.5
RL     50   80000    22642     22642     80000     80000    126415
RO      0
RS      9     565     3500      6900     12200     22642     56250     80000    102254    126415
RQ      9       0     1619      2777      4015      6165      9349     11617     14102     16000
RA      9     528     1283      2208      3208      5981     12555     15000     18017     20377
RE      9      57       60        62        64      66.3        70      71.5     73.36      74.5
R3 1.732    1.972    3.294     5.148     8.092      6.37    -2.857    -1.146     2.302     3.966
R3 2.236    1.828
P1     50   45000     1.15         3        54         0      .787        .3
P2      0     340        0         0
PR 10957    10050    10957     13821     13103     21489     24295     23343     22124     15245
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PR 12909   13339       0       0
PP 30000   45000   45000   45000
PS    12    15.9    17.2    20.5
CP    50    2000       0       0       0       0
IDUIAM DAM
C1    20   1.927       0       0
RT    50      60       0     1.2      .5       0       0       0
RL    60  187000  105000  105000  187000  187000  220829
RO     0
RS     9   55000   71086   91857  105000  118571  150200  187000  203914  220829
RQ     9       0    1824    4712    6420    8438   13295   19270   22822   26134
RA     9    5902    8045    9023   10000   10995   13947   17250   18308   20000
RE     9      41      43      45      46      47      49      51      52      53
R3 1.686    2.42   4.366   5.853   8.297   7.094  -2.982   -.474   3.747   4.734
R3 2.776   1.959
P1    60   79600    1.15       0      26      70    .838      .6
P2     0     370       0       0
PR 18103   16935   18103   22129   30489   34116   38112   37635   35499   24773
PR 23051   23820       0       0
CP    60    2000       0       0       0       0
IDCHONGPYONG DAM
C1    20   2.474       0       0
RT    60      70       0     1.2      .5       0       0       0
RL    70  260000  244000  244000  262000  430000  556400
RO     3      35      45      55
RS     9   10943   34717   60377  128301  208000  244000  262000  430000  436000
RQ     9       0    2500    8762   15800   23989   26648   28069   39253   46243
RA     9     787    6300   13529   22745   32157   36274   38800   54300   54700
RE     9       9      15      18      21      24      25    25.5    29.5      32
R3 1.686    2.42   4.366   5.853   8.297   7.094  -2.982   -.474   3.747   4.734
R3 2.776   1.959
P1    70   80000    1.15       0    10.5       0     .87      .3
P2     0     800       0       0
PR 14292   13370   20485   39648   33348   32272   47639   47639   43798   19056
PR 18902   19056       0       0
CP    70    4000       0       0       0       0
IDPALDANG DAM
RT    70      35       0     1.2      .5       0       0       0
OR    70      55       0     1.2      .5     .65       0   31.63       0
CP    35    4000  156.27  -114.7       0       0
IDMISARI ISLAND
C1    70   1.007       0       0
RT    35      45       0     1.2      .5       0       0       0
OR    35      45       0     1.2      .5    .648       1       0       0
QD    12   39.68   39.68   39.68   40.49   41.57   41.02   40.81   41.03   40.17
QD 40.24   39.68   39.68
QM154.38  154.38  154.38  155.19  156.27  155.72  155.51  155.73  154.87  154.94
QM154.38  154.38       0       0
CP    45    4000   127.7   127.7       0       0
IDINDOGYU GAGE
C1    70   1.056       0       0
RT    45      55       0     1.2      .5       0       0       0
CP    55    4000  170.77  -100.8       0       0
IDHAN RIVER BRIDGE
C1    70   1.069       0       0
RT    55               0     1.2      .5       0       0       0
OR    55               0     1.2      .5      .5       1       0       0
QD    12    0.00    0.00    0.00   30.06   59.97   49.45   41.87   50.30   18.26
QD 20.79    0.00    0.00
QM 100.8   100.8   100.8  130.85  170.77  150.25  142.67   151.1  119.06  121.59
QM 100.8   100.8
ED
BF     1     492       0        090010100      0     720       0       1
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IN	0517	9.20	10.2	25.3	40.9	73.6	20.0	378.1	53.6	360.5	25.5	12.9	7.71
IN	0518	5.63	9.15	26.0	40.8	92.7	104.5	931.6	282.3	43.6	21.1	25.4	14.8
IN	0519	8.84	7.21	16.0	29.7	53.4	223.3	555.2	167.4	120	86.9	17.6	8.68
IN	0520	9.37	13.4	82.9	148	70.5	120.5	969.7	389.5	147.1	34.9	20.8	15.8
IN	0521	10.6	9.49	46.5	118.3	83.2	70.4	770.8	166.5	200.7	53.5	28.8	28.7
IN	0522	16.2	71.9	58.8	117.1	69.4	72.5	1334.6	479	134.3	59.9	31.1	18.5
IN	0523	29.0	48.7	223.4	207.4	61.0	14.1	871.5	166.8	485.8	42.0	63.1	35.3
IN	0524	18.0	59.6	23.0	143.4	56.9	45.5	505.5	55.9	34.8	17.5	12.8	12.5
IN	0525	9.57	8.51	20.9	32.8	68.7	116.2	1504.1	371.8	395.6	53.4	38.1	45.5
IN	0526	42.5	32.3	82.4	130.4	147.4	61.5	1027.6	980.2	439.9	118.2	54.2	37.6
IN	0527	59.2	29.4	87.0	235.6	364.3	37.5	191.8	401.2	173.3	85.1	36.4	28.0
IN	0528	48.1	31.5	107.1	58.3	26.9	50.4	77.2	61.6	414.5	68.5	51.4	43.0
IN	0529	24.2	19.6	40.7	61.6	48.1	123.3	243.2	201.5	80.9	35.5	23.8	102.6
IN	0530	43.8	48.7	206	476.9	190.5	43.0	1666.1	429.7	196.2	53.9	46.5	32.9
IN	0531	30.2	36.6	96.6	331.3	204.5	100	422.6	467.9	153.2	59.6	58.6	66.7
IN	0532	70.4	52.7	84.2	132.6	56.7	43.9	178.6	289.3	144.3	48.5	35.6	29.7
IN	0533	25.9	20.3	50.7	127.7	263.2	263.3	496.1	596.5	363.7	135.6	58.1	48.3
IN	0534	31.3	30.0	86.1	155.5	177.3	164.2	835.3	496.1	220.6	200.8	55.7	44.5
IN	0535	41.2	29.3	63.6	118	57.2	100.8	557.3	273.2	112.7	44.6	45.4	31.4
IN	0536	15.8	8.37	39.4	212.4	112.6	23.5	164.4	1628.8	915.7	122.7	52.1	51.7
IN	0537	18.3	14.8	37.2	282.8	132.8	56.2	598.1	184.4	113.4	72.0	71.5	40.2
IN	0538	24.7	31.1	185.1	89.1	90.5	257.9	393.2	95.2	360.5	112.4	49.2	30.2
IN	0539	15.7	31.0	49.0	89.6	95.5	44.5	54.6	43.4	35.4	28.4	39.1	30.4
IN	0540	21.3	17.2	36.7	99.3	59.9	54.5	1792.5	138.5	307.3	59.7	44.0	37.9
IN	0556	16.54	19.14	318.7	253.8	108.71	504.33	944.26	134.65	256.33	47.98	22.52	12.49
IN	0557	12.52	12.30	32.49	203.3	49.08	27.70	954.47	441.61	64.76	47.28	58.92	45.63
IN	0558	24.34	30.42	111.77	158.51	104.17	17.29	308.04	317.45	778.78	210.51	160.39	82.09
IN	0559	54.23	69.85	358.03	335.95	207.78	50.00	1006.0	241.37	674.97	52.48	34.91	34.99
IN	0560	18.68	15.29	39.70	116.96	109.85	257.34	494.48	49.68	99.70	68.35	56.98	46.67
IN	0561	17.93	15.88	119.35	228.74	72.41	47.32	663.09	319.13	253.77	262.45	144.79	32.55
IN	0562	38.00	36.60	42.17	112.34	44.97	54.85	66.00	416.91	563.23	79.23	38.38	28.43
IN	0563	13.72	12.44	28.50	370.27	193.29	439.01	938.77	259.68	55.47	26.44	17.03	16.64
IN	0564	15.66	11.30	34.91	797.53	209.54	92.74	667.91	395.73	801.57	113.07	47.43	25.60
IN	0565	15.89	16.75	35.68	45.10	36.61	16.67	931.85	157.31	55.74	24.45	50.64	22.65
IN	0566	10.48	23.36	173.77	54.48	75.44	100.12	727.16	339.62	526.13	60.38	54.47	38.72
IN	0567	16.79	29.53	65.52	138.13	76.43	36.47	251.29	159.93	388.57	47.35	36.84	45.68
IN	0568	14.15	10.04	33.97	60.46	19.82	35.24	309.65	330.65	109.55	128.27	106.30	47.71
IN	0569	24.19	54.95	125.98	480.10	186.91	42.83	399.46	859.45	279.13	71.07	29.48	22.99
IN	0570	10.53	21.18	26.47	75.96	59.39	60.85	609.35	326.74	737.07	82.83	57.79	38.70
IN	0571	22.04	25.83	69.64	83.46	135.44	44.55	766.58	391.23	120.45	43.50	22.25	12.64
IN	0572	26.42	45.99	225.72	269.58	116.30	26.00	78.29	1197.9	507.23	153.52	256.20	113.71
IN	1517	23.1	17.3	37.4	55.0	105.9	30.1	433.5	116.1	534.2	46.9	28.5	19.0
IN	1518	12.1	14.7	43.2	61.2	119.2	130.7	1015.0	484.5	74.6	38.4	44.3	29.2
IN	1519	18.2	16.0	29.5	49.7	99.0	264.8	699.8	183.6	179.8	141.0	48.0	31.9
IN	1520	28.6	37.5	111.8	195.5	96.3	182.5	1341.6	705.4	245.1	77.0	59.1	33.0
IN	1521	24.40	23.20	73.20	167.60	108.00	93.20	859.40	205.00	252.50	79.00	47.80	43.60
IN	1522	27.00	91.00	85.00	162.40	107.50	100.50	1651.6	958.40	211.00	87.00	56.30	37.70
IN	1523	36.10	53.00	251.00	272.80	96.50	27.10	1081.4	332.50	593.70	69.60	97.70	55.40
IN	1524	30.80	86.60	41.90	190.10	96.10	74.50	910.80	97.20	55.00	32.50	25.70	25.10
IN	1525	18.90	17.90	35.20	51.10	107.80	159.20	2385.0	599.90	579.40	112.00	32.70	90.70
IN	1526	82.40	70.30	138.20	192.80	230.70	100.90	1411.7	1441.7	701.20	208.30	129.60	77.90
IN	1527	100.30	63.30	142.80	329.50	461.40	77.60	486.30	623.60	252.20	133.10	77.70	53.40
IN	1528	91.30	37.60	167.20	103.10	56.60	80.20	168.80	116.70	562.70	119.10	107.20	32.30
IN	1529	49.50	46.10	77.20	110.40	97.40	156.20	393.10	310.40	154.50	78.40	56.20	145.60
IN	1530	78.90	84.20	298.10	573.90	300.10	82.50	2314.0	587.20	301.30	99.20	38.40	58.00
IN	1531	56.10	52.00	149.50	403.30	328.90	143.00	573.20	826.40	264.00	103.10	113.30	112.30
IN	1532	114.40	90.80	134.00	193.60	100.10	84.50	297.10	416.20	276.60	107.90	79.80	54.30
IN	1533	54.20	41.60	83.30	190.10	345.60	337.30	748.80	844.80	576.60	191.00	102.60	35.80
IN	1534	59.40	55.20	138.00	237.40	246.90	218.60	1061.7	806.70	372.40	283.70	103.00	32.00
IN	1535	77.10	55.90	104.30	164.40	100.10	197.50	849.50	493.90	171.70	84.40	84.70	59.10
IN	1536	32.60	24.90	69.80	340.60	158.20	53.10	314.00	2325.9	1242.0	200.9	103.50	130
IN	1537	59.6	63.0	197.5	422.9	201.5	93.9	754.5	398.9	242.5	136.0	127.4	75.1
IN	1538	48.9	54.0	314.9	150.2	159.6	379.7	609.7	170.9	455.1	169.5	39.6	65.3

IN	1539	43.6	56.4	85.1	141.1	173.2	83.7	98.0	69.8	67.1	58.3	72.0	55.7
IN	1540	42.5	37.3	64.2	149.5	105.1	96.4	2972.6	275.7	668.4	98.2	76.3	65.8
IN	1556	43.0	43.0	360.2	489.93	194.73	616.45	1749.7	194.61	379.13	69.36	41.46	26.7
IN	1557	24.9	27.4	38.4	231.5	62.74	40.5	1330.7	497.23	92.85	60.22	69.34	50.58
IN	1558	60.65	56.63	136.48	221.15	149.67	30.65	589.0	595.74	1177.6	300.32	278.5	180.58
IN	1559	141.03	137.92	448.35	419.27	309.46	86.32	1354.8	408.73	915.18	108.81	71.11	57.25
IN	1560	47.31	38.69	68.19	157.96	149.28	298.91	646.03	86.34	132.85	102.12	81.25	75.57
IN	1561	42.32	36.51	156.05	298.0	102.24	70.32	973.24	515.97	415.9	346.61	203.71	138.32
IN	1562	69.90	101.7	64.45	175.53	65.2	53.89	114.25	567.83	758.2	153.43	55.78	45.38
IN	1563	34.41	37.10	41.27	470.97	276.14	644.35	1324.5	370.32	98.95	56.32	45.48	43.59
IN	1564	41.78	35.71	55.81	1090.6	270.91	112.45	973.91	647.55	1131.4	177.85	54.61	35.74
IN	1565	31.79	29.05	44.2	39.21	36.81	26.32	1370.3	304.39	90.49	49.67	106.59	43.18
IN	1566	24.06	35.61	279.82	109.14	101.3	133.65	1319.6	531.55	719.20	91.08	82.86	49.51
IN	1567	34.15	55.38	132.33	230.4	118.53	45.5	388.43	310.43	504.0	82.78	65.52	79.15
IN	1568	22.79	14.74	53.74	88.45	15.75	30.93	465.02	474.65	198.89	184.27	183.17	73.54
IN	1569	35.99	137.72	191.72	600.07	337.07	55.15	509.07	1411.4	540.07	125.08	42.39	30.49
IN	1570	16.12	43.49	35.32	101.99	87.29	64.02	1014.7	447.23	1102.3	195.99	103.87	73.54
IN	1571	39.50	38.89	143.1	153.06	214.99	81.75	1236.4	612.39	235.77	93.44	42.24	33.66
IN	1572	47.02	78.29	258.91	361.13	183.5	55.32	134.24	1639.5	677.07	313.29	368.60	260.05
IN	2017	10.4	10.1	16.7	23.7	53.6	11.3	117.6	71.3	307.1	33.9	19.0	12.6
IN	2018	8.8	10.8	19.0	19.3	27.8	28.3	325.9	234.8	55.9	22.2	21.8	14.4
IN	2019	9.3	10.0	17.5	32.6	72.0	91.4	60.6	31.5	104.2	105.6	25.3	14.8
IN	2020	10.4	17.3	43.3	67.6	45.5	95.7	285.6	250.3	166.3	38.3	43.0	21.1
IN	2021	15.7	14.2	34.7	42.1	45.3	31.1	110.0	52.2	95.9	36.0	17.6	15.3
IN	2022	11.2	21.4	35.7	100.3	39.8	50.1	320.7	593.6	127.7	34.4	26.2	16.6
IN	2023	12.9	16.7	44.4	79.7	39.7	10.3	255.0	367.9	90.0	19.7	38.6	25.3
IN	2024	12.9	44.2	15.8	72.0	53.4	38.5	613.4	46.2	16.3	13.0	12.1	11.3
IN	2025	8.5	7.1	9.5	21.8	60.8	61.0	835.6	194.9	263.5	53.4	39.5	45.3
IN	2026	36.2	29.8	45.0	51.4	116.9	19.9	458.7	444.3	81.2	84.8	35.7	23.3
IN	2027	51.9	48.2	64.6	115.0	133.5	40.9	357.9	325.8	95.1	42.5	32.5	9.3
IN	2028	27.8	31.5	71.4	39.7	21.1	20.0	102.7	64.0	135.5	39.9	50.6	33.9
IN	2029	16.2	8.3	19.1	41.0	47.9	43.5	246.8	151.6	101.9	26.9	22.5	43.5
IN	2030	25.9	30.1	94.8	69.1	106.4	25.5	488.4	97.8	98.8	31.9	27.6	24.7
IN	2031	17.1	19.2	39.0	63.5	94.8	35.3	99.7	281.9	133.9	37.3	42.1	32.6
IN	2032	48.5	30.7	59.4	88.7	41.4	34.1	169.5	239.7	165.9	121.7	76.4	44.0
IN	2033	34.3	29.5	34.0	89.6	86.2	137.0	169.5	289.4	320.6	50.5	40.5	25.8
IN	2034	17.5	18.2	44.4	90.3	97.1	103.4	224.4	397.3	153.6	93.0	32.0	29.3
IN	2035	23.4	20.3	36.8	37.4	44.5	158.5	283.8	300.6	72.9	36.0	35.1	23.1
IN	2036	16.1	16.5	17.3	67.5	65.0	13.2	408.1	519.0	390.4	92.3	37.5	94.1
IN	2037	29.3	20.8	32.7	122.2	44.2	17.0	215.4	199.1	123.6	39.3	45.1	31.5
IN	2038	24.3	17.2	127.3	66.0	54.3	102.2	235.0	89.9	82.3	28.4	23.0	16.7
IN	2039	12.3	14.3	22.1	40.8	93.4	62.5	50.6	19.0	35.1	32.2	27.7	32.2
IN	2040	29.9	19.8	21.7	54.4	45.0	41.8	787.4	112.0	255.2	50.4	44.5	38.1
IN	2056	7.6	10.5	183.0	143.3	40.0	150.9	321.0	69.0	152.0	29.0	14.6	13.5
IN	2057	12.2	17.0	18.9	65.9	24.5	21.8	135.6	253.8	48.4	33.6	36.2	24.5
IN	2058	17.5	17.8	49.9	65.3	35.8	15.0	145.9	138.1	243.9	95.8	51.7	31.1
IN	2059	18.4	22.9	145.5	194.7	67.0	36.5	223.6	224.2	325.0	44.5	37.9	24.7
IN	2060	13.5	16.3	38.8	55.7	41.5	100.4	284.3	101.9	62.8	43.5	30.9	25.3
IN	2061	14.8	16.6	30.8	92.0	51.2	38.5	250.9	354.5	188.5	60.3	83.0	45.9
IN	2062	19.5	21.1	33.5	107.4	28.4	36.8	186.2	454.5	306.4	42.3	25.3	18.6
IN	2063	16.3	19.1	29.6	270.4	120.3	186.5	737.0	170.1	42.5	18.3	14.3	12.9
IN	2064	14.8	11.8	20.7	498.5	115.5	59.3	670.4	468.7	264.3	61.3	26.5	14.9
IN	2065	11.4	13.1	27.5	41.5	21.8	8.9	717.8	372.5	85.8	23.7	29.2	11.2
IN	2066	6.5	16.2	46.6	52.7	35.0	160.5	931.3	361.9	395.8	50.2	26.4	14.5
IN	2067	8.7	10.2	59.1	72.2	55.5	29.0	325.4	401.0	181.2	33.2	17.0	12.2
IN	2068	10.2	9.4	22.1	31.0	15.5	26.0	210.1	251.8	111.9	192.3	59.7	38.5
IN	2069	17.3	20.3	49.0	282.4	205.3	66.3	403.0	499.7	57.8	25.2	17.6	10.9
IN	2070	8.3	11.0	17.9	26.5	13.0	17.3	325.3	244.5	553.3	51.5	44.1	25.1
IN	2071	13.0	14.0	34.4	51.2	59.1	44.5	401.7	261.7	209.0	53.1	28.4	17.5
IN	2072	15.3	18.4	61.9	130.6	29.3	22.5	132.0	773.4	168.3	57.2	55.7	49.1
IN	4017	6.3	6.4	11.5	13.7	31.4	8.1	29.3	48.7	152.4	18.3	12.5	9.0
IN	4018	6.2	7.9	10.3	14.0	20.7	15.2	172.1	209.5	30.8	13.7	12.5	9.5
IN	4019	5.9	6.5	11.4	18.9	51.6	45.3	38.9	47.4	45.5	42.5	14.7	10.5

IN	4020	7.2	13.4	32.7	47.5	30.5	63.8	243.4	217.7	45.1	27.5	19.3	15.0
IN	4021	9.9	8.1	18.6	31.6	15.9	15.8	85.5	29.6	39.7	19.9	12.0	9.3
IN	4022	7.2	16.0	21.3	39.3	36.8	35.3	252.4	259.9	59.4	27.0	14.2	11.5
IN	4023	11.5	11.3	42.3	48.2	30.1	9.7	138.5	143.0	124.6	13.6	29.7	23.4
IN	4024	11.4	31.5	4.7	52.3	36.0	26.0	239.3	27.9	11.2	7.9	7.3	7.8
IN	4025	5.9	4.8	7.4	14.9	46.3	37.5	681.7	133.8	138.9	36.1	27.8	29.6
IN	4026	24.6	21.2	34.9	39.0	62.0	24.3	284.5	214.7	150.5	45.9	35.7	16.0
IN	4027	40.7	32.0	38.6	122.7	82.7	36.3	272.2	171.7	72.9	27.3	20.7	19.6
IN	4028	27.8	21.3	51.7	27.1	14.8	13.5	65.0	26.0	152.8	31.9	32.8	22.6
IN	4029	10.9	5.7	14.7	32.1	26.1	35.0	71.5	85.9	45.6	19.2	15.9	32.4
IN	4030	17.4	19.4	83.3	97.2	64.8	18.3	153.1	134.0	55.9	24.5	22.9	15.1
IN	4031	11.5	13.3	44.9	89.9	83.0	23.5	174.0	321.5	102.6	24.5	57.9	34.6
IN	4032	35.8	22.7	46.6	50.3	36.6	25.5	59.4	117.2	96.8	29.5	22.7	30.6
IN	4033	23.1	20.5	22.7	54.5	109.4	86.6	157.2	180.3	131.2	42.3	22.4	19.7
IN	4034	11.9	12.3	34.7	51.5	57.9	37.4	115.6	206.1	115.7	67.5	30.3	22.1
IN	4035	16.5	13.8	24.9	33.6	32.8	87.2	309.9	114.5	31.7	20.5	24.2	15.5
IN	4036	10.7	11.7	13.1	113.8	32.8	8.2	80.6	358.0	257.7	35.3	30.3	33.0
IN	4037	22.0	15.8	20.3	94.9	35.1	10.9	97.4	91.5	128.1	33.2	30.8	22.0
IN	4038	16.9	12.4	126.3	44.9	46.3	91.4	137.8	42.0	55.2	21.5	14.5	13.2
IN	4039	10.6	12.0	18.2	34.0	86.2	42.5	36.1	17.5	25.3	19.2	24.9	11.9
IN	4040	11.0	12.0	15.2	44.9	31.1	32.0	688.8	74.1	151.8	33.1	27.7	25.5
IN	4056	7	9	135	137	33	75	177	15	55	33	15	10
IN	4057	10	8	14	53	19	23	108	235	52	22	16	5
IN	4058	11	11	38	56	20	15	107	49	215	44	15	9
IN	4059	11	16	117	279	40	39	197	124	221	25	16	22
IN	4060	12	12	29	51	35	77	457	148	76	28	18	16
IN	4061	11	11	19	69	53	13	84	208	92	62	22	14
IN	4062	13	12	23	174	27	34	309	130	148	19	25	14
IN	4063	11	14	19	98	111	142	719	305	26	16	21	10
IN	4064	10	6	16	216	88	70	618	111	68	27	21	15
IN	4065	10	6	18	56	18	12	498	180	57	10	14	12
IN	4066	6	9	36	52	24	44	564	365	334	50	30	8
IN	4067	7	9	51	82	51	33	195	227	155	34	24	17
IN	4068	7.6	4.6	18.2	31.2	13.1	17.0	188.0	272.8	105.4	20.8	70.0	38.0
IN	4069	16.0	16.0	46.0	262.0	152.0	55.0	256.0	116.0	72.0	27.0	16.0	10.0
IN	4070	9.0	11.8	17.0	34.7	24.3	25.7	373.8	87.0	515.0	38.8	37.0	16.6
IN	4071	11.3	10.3	29.3	43.7	67.0	29.3	262.2	227.0	114.8	31.5	18.1	14.0
IN	4072	12.7	19.0	83.0	142.0	27.0	13.0	25.0	60.7	83.0	39.0	22.0	4.0
IN	7017	70.5	41.9	79.2	105.7	220.2	65.8	651.7	330.2	1147.	120.2	82.0	57.3
IN	7018	34.3	34.2	102.7	127.2	198.1	227.1	1375.0	1186.0	182.0	98.1	139.5	78.7
IN	7019	50.1	46.1	76.2	119.3	257.8	423.1	1229.0	252.3	406.6	329.7	151.4	110.4
IN	7020	93.5	119.4	216.0	359.3	188.9	400.3	2671.0	1797.0	590.4	220.7	188.9	92.1
IN	7021	71.6	70.0	166.8	312.7	198.3	175.5	1223.0	348.1	395.2	168.6	113.9	102.6
IN	7022	64.5	161.7	177.8	324.4	241.1	200.3	2829.0	2605.0	475.3	183.0	143.5	103.7
IN	7023	62.4	71.8	362.8	493.9	220.7	71.9	1860.0	905.2	994.1	164.5	219.1	132.2
IN	7024	75.0	182.0	107.2	358.9	232.5	175.2	2324.0	240.1	125.8	84.0	74.2	69.0
IN	7025	51.1	49.9	84.8	115.0	244.4	313.0	5465.0	1396.0	1225.0	312.9	235.4	245.7
IN	7026	219.6	200.3	332.4	413.0	522.7	238.1	2787.0	3072.0	1614.0	520.3	330.1	216.1
IN	7027	243.1	179.2	337.2	657.3	818.4	214.3	1489.0	1403.0	555.5	301.3	219.2	184.1
IN	7028	242.4	278.4	377.5	258.2	158.5	184.3	482.0	306.5	1095.0	294.5	298.6	217.7
IN	7029	132.2	136.7	202.9	279.2	265.7	277.3	915.8	692.2	407.8	225.1	166.6	323.5
IN	7030	200.3	207.2	624.1	940.2	683.5	218.3	4628.0	1152.0	669.9	255.8	232.7	188.4
IN	7031	145.4	150.1	335.2	686.9	763.2	295.3	1114.0	2067.0	643.0	253.5	301.5	270.8
IN	7032	267.8	223.1	308.2	409.4	250.3	224.7	709.5	855.2	732.2	311.0	230.7	182.7
IN	7033	151.5	107.6	195.5	410.3	644.4	508.1	1638.0	1728.0	1321.0	388.6	255.9	215.5
IN	7034	155.9	142.2	319.3	525.1	495.3	418.9	1892.0	1890.0	899.9	578.9	265.4	216.7
IN	7035	201.1	147.4	246.0	330.3	248.3	529.9	2014.0	1257.0	414.6	221.4	220.3	154.3
IN	7036	90.1	81.1	175.2	788.4	364.0	155.9	829.3	4801.1	2401.0	473.5	280.2	396.5
IN	7037	199.5	235.6	345.9	916.9	443.7	225.0	1330.0	1133.0	712.3	356.3	299.5	195.5
IN	7038	132.0	133.4	765.5	362.2	398.9	309.9	1369.0	432.9	803.2	370.5	229.4	185.5
IN	7039	138.4	144.0	210.1	321.3	441.7	233.2	248.0	162.0	185.4	160.8	135.5	143.0
IN	7040	115.5	106.3	159.6	326.5	261.5	241.1	7079.0	746.5	1904.0	232.4	177.2	162.4
IN	7055	81.2	95.2	676.6	633.8	229.2	1303.0	2900.0	439.1	1055.0	179.0	102.0	95.2

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IN   7060 100.9 109.2 130.1 290.1 234.6 632.31294.0 227.5 250.5 208.0 149.2 124.8
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IN   7068   115    70   172  1506   467   157  3630  1679   698   252   270   261
IN   7069   183   183   522   694   522   745  1561   351   586   357   257   332
IN   7070   145   131    95   205   282  1234  3577   493   326    63    73    64
IN   7071    53    82   258   516   228   263  1486  2571  2739   615   359   234
IN   7072   210   138   777  1462   845   457  1335  1564   329   270   234   199
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